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Environmental Studies No 37

Reactions of Beluga Whales and Narwhals to Ship Traffic and Ice-Breaking along Ice Edges in the Eastern Canadian High Arctic : 1982-1984

Canada

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Reactions of Beluga Whales and Narwhals To Ship Traffic and Ice- Breaking along Ice Edges in the Eastern Canadian High Arctic : 1982-1984

Northern Affairs Program

LGL Limited
Environmental Research Associates

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Un résumé de cette publication peut être obtenue en français :
" Réaction des narvals et des bélugas `a la circulation maritime et au passage des brise-glaces la long de la banquise dans l'est de l'extrême-Artique canadien de 1982 à 1984 ".

PREFACE

This volume presents the results of a three-year study of the effects of arctic shipping on beluga whales and narwhals. The volume consists of four component reports beginning with an overview report of the results and main findings of the entire study. Subsequent components are the reports for each of the three years of research: 1982, 1983 and 1984. The four reports are

1. Finley, K.J. and R.A. Davis. 1984. Reactions of beluga whales and narwhals to ship traffic and ice-breaking along ice edges in the eastern Canadian High Arctic: 1982-1984. An overview. Rep. by LGL Limited, King City, Ontario, for Canada Department of Indian Affairs and Northern Development, Ottawa. 42 p.

2. Finley, K.J., C.R. Greene and R.A. Davis. 1983. A study of ambient noise, ship noise, and the reactions of narwhals and belugas to the MV *Arctic* breaking ice in Admiralty Inlet, N.W.T. - 1982. Rep. by LGL Limited, Toronto, for Canada Department of Indian Affairs and Northern Development, Ottawa. 108 p.

3. Finley, K.J., G.W. Miller, R.A. Davis and C.R. Greene. 1984. Responses of narwhals (*Monodon monoceros*) and belugas (*Delphinapterus leucas*) to ice-breaking ships in Lancaster Sound - 1983. Rep. by LGL Limited , King City, Ontario, for Canada Department of Indian Affairs and Northern Development, Ottawa. 117 p.

4. Miller, G.W. and R.A. Davis. 1984. Distribution and movements of narwhals and beluga whales in response to ship traffic at the Lancaster Sound ice edge - 1984. Rep. by LGL Limited, King City, Ontario, for Canada Department of Indian Affairs and Northern Development, Ottawa. 34 p.

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Section 1

Overview Report

INTRODUCTION

Rationale

In recent years there has been an increased awareness of, and concern for, the potential effects of shipping activities on marine mammals in the Arctic. Of particular concern have been proposals (Arctic Pilot Project, Dome Petroleum Limited) to ship hydrocarbons from the Arctic using large ice-breaking carriers that would operate year-round. In addition, there are smaller proposals to extend the open water shipping season in spring and fall through the use of icebreakers. The general concern is that the ice-breaking activities and underwater noise from the ships might affect marine mammals through disturbance and/or interference with underwater communication among the mammals. Previous to the present program, no studies of the effects of ships on marine mammals in the eastern Canadian Arctic had been conducted.

In the spring of 1982, Canarctic Shipping Ltd. announced plans to send the ice-breaking ore carrier MV Arctic through the ice in Admiralty Inlet to the Nanisivik lead-zinc mine. The purpose of this exploratory voyage was to determine the feasibility of increasing the length of the shipping season to the mine. Earlier access to the mine would allow more ore shipments per year, thereby improving the economics of the mining venture.

The proposed voyage raised concerns among the Inuit hunters of Arctic Bay who hunt narwhals in spring along the ice edge across Admiralty Inlet and in the ice cracks in Admiralty Inlet. The hunters were worried that the MV Arctic might frighten the narwhals away from the ice edge and cause the animals to move to different areas that were not accessible to the hunters. A related concern was that the ship might directly interfere with hunting activities. In response to the specific concerns of the Arctic Bay hunters and the broader concern about arctic shipping in general, the Northern Affairs Program of the Department of Indian Affairs and Northern Development organized a study of the responses of narwhals and belugas to the MV Arctic during her exploratory voyage into Admiralty Inlet in June 1982. The study was continued in June of 1983 and 1984 to take advantage of additional probes by the MV Arctic and accompanying icebreakers of the Canadian Coast Guard.

General Approach

The spring migration of narwhals and belugas in the High Arctic is determined by ice conditions. Narwhals enter Lancaster Sound and proceed to major summering areas in Admiralty Inlet and channels farther to the west. The narwhals usually arrive before the fast ice breaks up in Lancaster Sound and Admiralty Inlet. Narwhals are found along fast-ice edges and in adjacent waters while they wait for cracks and leads to form in the fast ice. The summering grounds for belugas are in the central Arctic and they use the northern coastal waters of Lancaster Sound as a migration route to these areas. In years when a fast-ice edge occurs across Lancaster Sound, belugas concentrate in high densities along the edge while they wait for cracks and leads to form. (The above brief synopsis is based on observations in nine years--see Davis et al. 1978; Davis and Finley 1979; Koski 1980; Finley et al. 1984 for detailed reviews.)

Our studies were designed to take advantage of the presence of these fast-ice edges. The whales were concentrated in these areas and the ice provided a semi-solid platform for biological observations at the point where the arriving ships were forced to begin ice-breaking activities.

Our basic study approach involved documenting the undisturbed behaviour of the whales along the ice edge before the ship(s) arrived. We then documented changes in the normal behaviour when the ships arrived and during periods when there was ship activity in the area. Whales were also monitored during a short post-disturbance period to examine the return to normal patterns of behaviour and distribution. We used three basic techniques to gather information on whale behaviour and ship-induced changes to the whales' environment. Aerial surveys were flown along the ice edges (and in offshore waters in 1984) to document large scale patterns of distribution and movement of the whales. Biologists stationed on the ice edge collected detailed information on the surface and diving behaviour of the whales. Hydrophones were deployed under the ice to document the underwater vocalizations of belugas and narwhals in undisturbed situations and when the ships were present in the area. The hydrophones were also used to document the natural (ambient) levels of underwater noise and the levels of underwater noise emanating from the ships.

Scope of Report

The present report is intended to provide a general overview of the three year study of the effects of ships and icebreaking on beluga whales and narwhals. It is designed to give the reader a general understanding of how the study was conducted, the main results of the study, and the principal conclusions that can be drawn. The results from the three years are integrated in the Discussion of the present report to form the basis of the main conclusions.

The present overview report is not intended to be a full technical treatise on the studies. Readers interested in the details of the technical approach and results should refer to the three annual reports on which this overview is based. Reference to these background reports is necessary to review the technical basis for the interpretations and conclusions presented in this report. The citations for the background reports are given at the end of the Introduction.

Study Sponsors

The project was coordinated and managed by the Northern Environmental Protection Branch of DIAND. The various phases of the project were funded by a variety of companies and agencies as noted below.

	Study Component			
Agency	1982	1983 field	1983 office	1984
DIAND	X	X	X	X
Arctic Pilot Project	X	X	X	-
Canadian Coast Guard	-	X	X	-
Canarctic Shipping Ltd.	X	X	-	-
Consolidex-Magnorth-Oakwood	-	X	-	-
Dome Petroleum Ltd.	-	X	X	-
Environment Canada	X	X	-	-
Gov't. N.W.T.	X	-	-	-
Gulf Canada Resources Inc.	-	X	X	-

In addition to the above sponsors, many other people and organizations assisted with the studies reviewed here. Detailed acknowledgements for this help are found in each of the component annual reports. Two groups of subcontractors deserve special mention here.

Avatauq Inc. of Arctic Bay, its president Glenn Williams, and the hunters of Arctic Bay provided essential logistic support and advice on ice conditions and safety. Dr. C.R. Greene, Greeneridge Sciences Inc. of Santa Barbara, was responsible for collection and analyses of underwater data on ambient noise and ship noise.

Supporting Documents

The present report is based on the more detailed technical reports describing each of the three years of study. An additional report on ship noise and transmission loss has also been prepared by C.R. Greene (1984). The citations for the three annual reports are listed below.

Finley, K.J., C.R. Greene and R.A. Davis. 1983. A study of ambient noise, ship noise, and the reactions of narwhals and belugas to the MV *Arctic* breaking ice in Admiralty Inlet, N.W.T. - 1982. Rep. by LGL Limited, Toronto, for Canada Department of Indian Affairs and Northern Development, Ottawa. 108 p.

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METHODS

The following sections provide brief summaries of the study areas and methods used in the three years of study. The reader is referred to the background annual reports for full technical details.

Study Areas

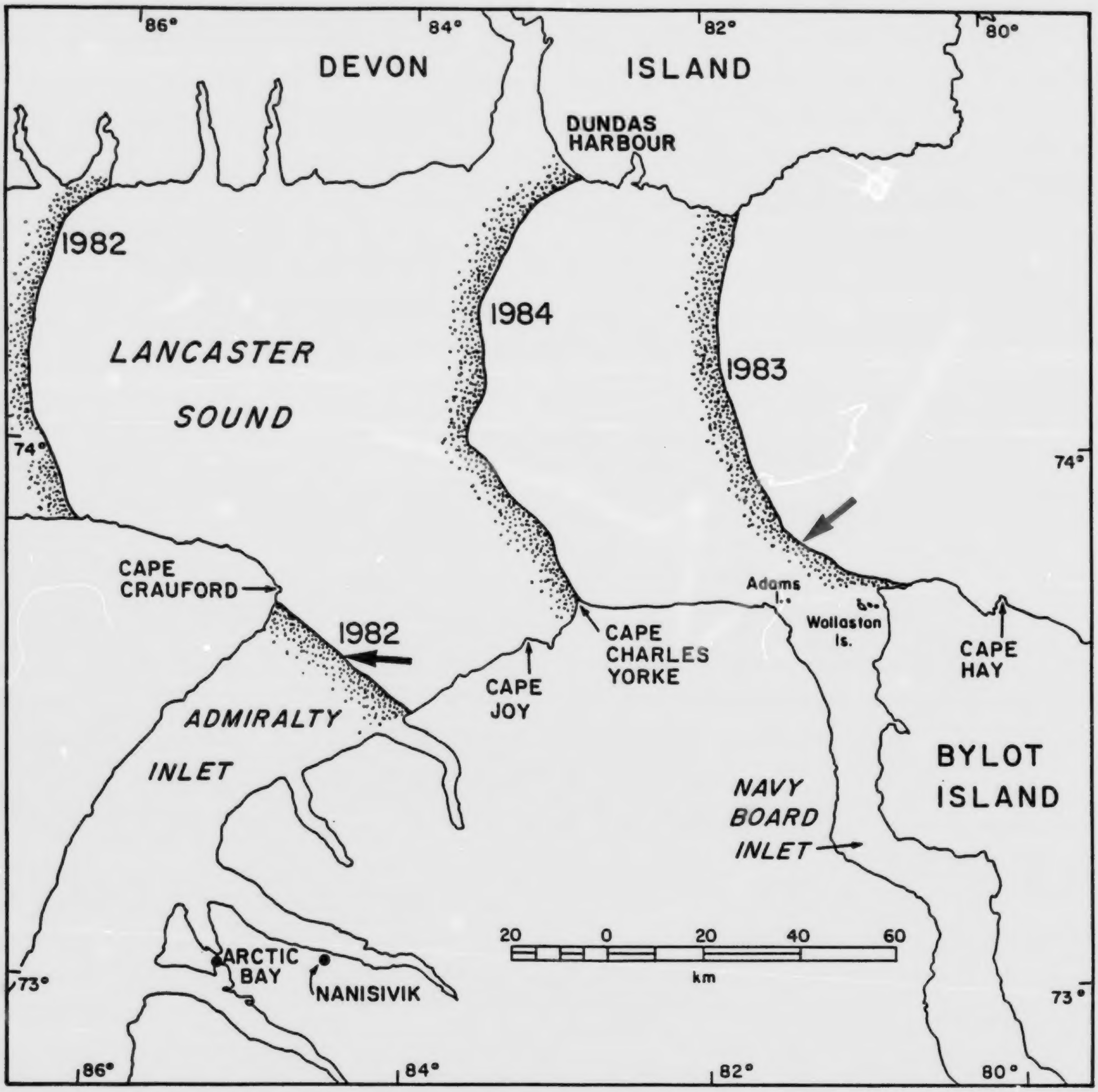
Ice conditions were different in each of the three years of study. The locations of the major ice edges studied are shown in Figure 1. The situation in 1982 was more typical of average ice conditions in that the major ice edge across Parry Channel (Lancaster Sound-Barrow Strait) was to the west of Admiralty Inlet. In this situation the ore carrier MV Arctic encountered only loose ice in Lancaster Sound; it did not begin continuous ice-breaking until it entered the fast ice at the mouth of Admiralty Inlet. In 1982, the Arctic was accompanied by the icebreaker CCGS John A. MacDonald but the icebreaker remained offshore in Lancaster Sound since the Arctic encountered little difficulty in breaking through the ice in Admiralty Inlet to reach the mine at Nanisivik.

In 1983, the Arctic was again accompanied by the icebreaker CCGS John A. MacDonald. The ice edge was across the east end of Lancaster Sound and ice conditions were very severe. The Arctic was unable to break through the ice in Lancaster Sound and the MacDonald took over ice-breaking duties and escorted the Arctic into Admiralty Inlet.

In 1984, the ice edge was again east of Admiralty Inlet. The Louis St. Laurent accompanied the Arctic into the ice but the Arctic was able to break her own track into Nanisivik while the Louis St. Laurent remained in the ice at the mouth of Admiralty Inlet.

Description of Ships

The MV Arctic is an icebreaking ore carrier of about 20,000 deadweight tonnes and is 209.5 m long with a draft of 11 m. The ship is powered by a single diesel engine producing 14,770 HP on a single shaft with a single variable pitch propeller.



86°
84°
82°
80°
DEVON
ISLAND
DUNDAS HARBOUR
1982
1984
1983
LANCASTER SOUND
74°
74°
CAPE CRAUFORD
1982
Adams Is.
Wollaston Is.
CAPE CHARLES YORKE
CAPE JOY
CAPE HAY
ADMIRALTY INLET
BYLOT ISLAND
NAVY BOARD INLET
20
0
20
40
60
km
ARCTIC BAY
NANISIVIK
73°
73°
86°
84°
82°
80°

Fig. 1. Locations of the major ice edges (stippled) in the Lancaster Sound area in late June and early July, 1982, 1983 and 1984. Principal ice-based study areas are noted by arrows.

The icebreaker CCGS John A. MacDonald is 96 m long with a draft of 8.6 m and a deadweight of 3685 tonnes. The ship is powered by nine diesel electric engines producing 15,000 HP over three shafts with fixed-pitch propellers. The icebreaker CCGS Louis St. Laurent is 111.7 m long with a draft of 9.45 m and a gross registered tonnage of 10,908 tonnes. The ship is powered by steam turbines producing 24,000 HP over three shafts with fixed-pitch propellers.

Data Collection Techniques

Aerial Surveys

Aerial surveys were conducted in each of the three years of study. In 1982 and 1983, a turbine helicopter (Bell 206B) was used. A helicopter was necessary since between surveys the observers were making observations from the ice edge and could only be reached by helicopter. The helicopter was adequate for surveys along solid ice edges and coasts but for safety reasons it could not fly offshore over open water. Another drawback of the helicopter was that it was not equipped with an accurate navigation system for determining its location and the locations of whales along the ice edge.

In 1984, when no ice parties were present, we used a de Havilland Twin Otter equipped with a GNS-500 navigation system for the aerial surveys. Thus, we were able to obtain more precise survey results in terms of the locations of whales. We were also able to survey offshore areas.

Standard aerial survey techniques were used and results are comparable with other studies conducted in the High Arctic. Details of the techniques are presented in the background reports.

Ice-based Observations

Detailed observations of whale behaviour were made by biologists stationed at the ice edge in 1982 and 1983. These observations produced data on general behaviour, dive times, surfacing and respiration rates, social behaviour, rates of movement, and individual identifications of well-marked animals. The data base encompasses belugas and narwhals in undisturbed conditions when ships are absent, in situations when ships are present and operating, and in situations when ships are present but not operating.

Acoustic Sampling

Hydrophones were deployed beneath the ice in 1982 and 1983 to document the underwater noise environment that is so important to marine mammals. Tape recordings of the sounds on the hydrophones were made for later analyses in the laboratory. Generally, two hydrophones were used simultaneously at depths of 3 m and 20 m below the ice surface. Two types of hydrophones were used: a wideband U.S. Navy model H56 hydrophone, useful for sounds in the frequency ranges used for whale communications, and a low noise bender hydrophone, which was particularly useful for the low frequency noises produced by ships. Three types of acoustic data were collected and analyzed.

Whale Vocalizations

The complex vocal repertoires of belugas and narwhals were documented during the study. To the extent possible, whale vocalizations were related to observed surface behaviour of the animals and the context in which various calls were used was examined. Changes in the vocal behaviour of the whales when ships were present and operating were examined closely.

During analysis, the frequency content of the various whale calls was determined using a real-time spectrum analyzer. Also, quantitative and qualitative analyses of the numbers and types of vocalizations recorded in various control and experimental situations were performed.

Ambient Noise

The natural background levels of ambient noise in the absence of ships were determined at the Admiralty Inlet ice edge in 1982 and at the Lancaster Sound ice edge in 1983 (see Figure 1 for locations). Ten-minute samples were taken every two hours during the two studies, although some gaps in the record occurred because of changing ice conditions. A small number of samples of ambient noise levels under the ice from 11 to 18 km from the ice edge were also obtained. Analyses of ambient noise consist of band level analyses and spectrum level analyses. The data are suitable for the preparation of probability distributions of various levels of ambient noise but these were not required for the specific objectives of this study.

Ship Noise

Data from the hydrophones were used to document the frequency spectra of noise from the MV Arctic and the CCGS John A. MacDonald. We were also able to determine the levels of ship noise received by the whales that we were observing. Data are also available on the distance of the ship from the hydrophone when ship noise was first detectable. The various received levels of ship noise were related to the vocal behaviour and surface behaviour of the whales to evaluate the levels and/or content of noise to which the whales reacted. Although not an objective of the study, we were able to estimate the source noise levels of the MV Arctic breaking ice in 1982. A related study to determine transmission loss rates and the source noise levels of the John A. MacDonald is reported by Greene (1984).

Study Protocols

In each of the three years the studies varied in location and emphasis. The study protocols are briefly reviewed below.

1982

The study in 1982 was a small prototype effort organized with less than two week's notice between project approval and the arrival of the MV Arctic at the Admiralty Inlet ice edge. As a result of the late start-up and the fact that the field crew was stranded on a drifting ice pan, we had only one day to study the pre-disturbance normal behaviour of the whales and to collect data on ambient noise.

The details of the arrival of the MV Arctic on the second day are shown in Figure 2. Continuous visual observations of whale behaviour and regular acoustic recordings were made during the ship's approach. Observations and

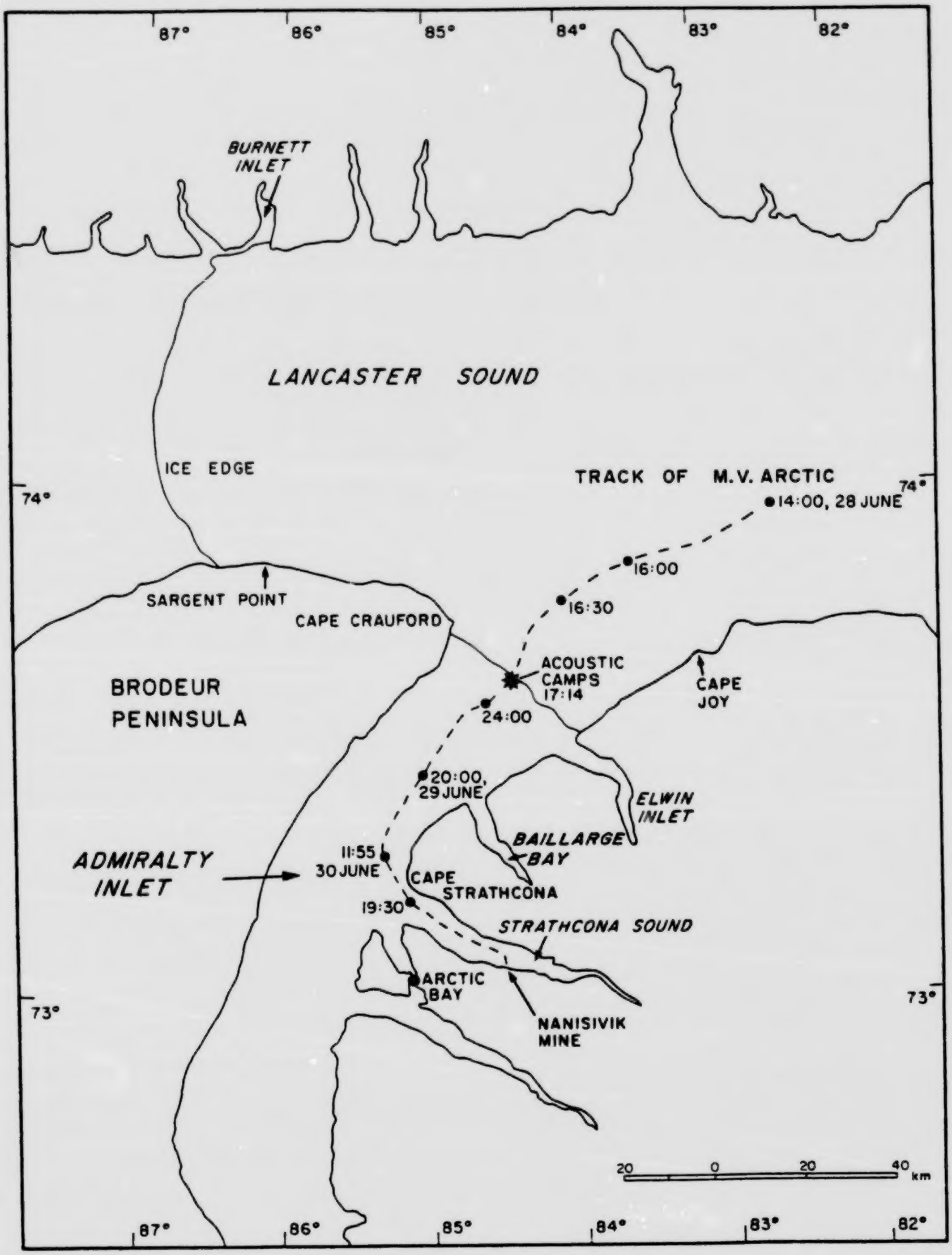

87°
86°
85°
84°
83°
82°
BURNETT INLET
LANCASTER SOUND
ICE EDGE
TRACK OF M.V. ARCTIC
74°
14:00, 28 JUNE
16:00
16:30
SARGENT POINT
CAPE CRAUFORD
ACOUSTIC CAMPS 17:14
CAPE JOY
BRODEUR PENINSULA
24:00
20:00, 29 JUNE
ELWIN INLET
BAILLARGE BAY
ADMIRALTY INLET
11:55 30 JUNE
CAPE STRATHCONA
19:30
STRATHCONA SOUND
ARCTIC BAY
NANISIVIK MINE
73°
20 0 20 40 km

Fig. 2. The 1982 study area showing the track of the MV Arctic between 28 and 30 June.

recordings were continued until after the Arctic reached Nanisivik and the return to normal whale behaviour and distribution patterns was documented.

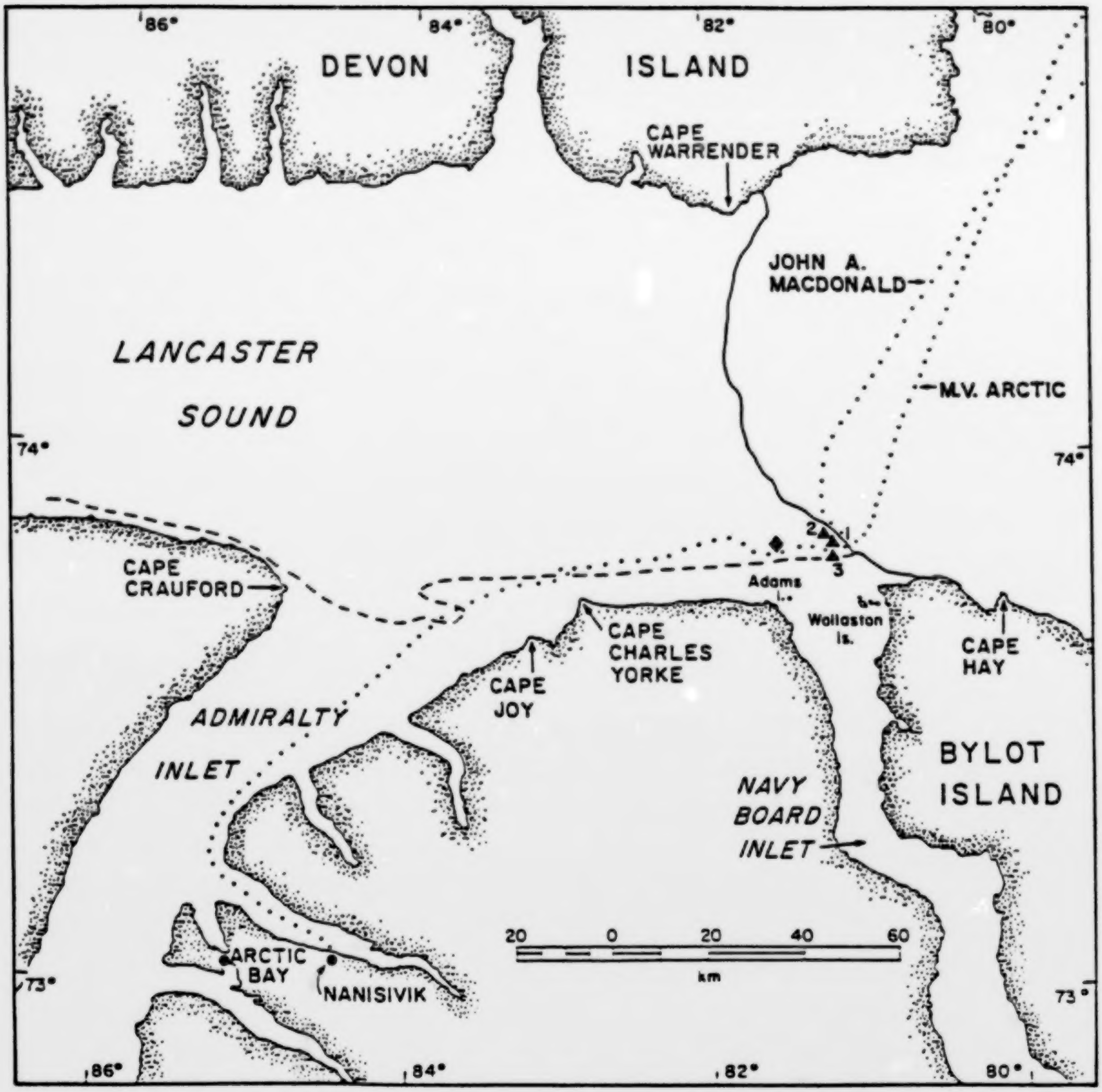
In 1982 we had access to a helicopter for aerial surveys only on an opportunistic basis. Thus, it was not possible to conduct surveys at the optimum times. Valuable surveys were conducted, however, 22 hours before and 28 and 52 hours after the MV Arctic reached the ice edge. The latter survey provided additional information on the responses of whales to the icebreaker CCGS John A. MacDonald which was stopped along the middle of the Lancaster Sound ice edge.

1983

The study in 1983 was a larger, more comprehensive effort focused on the Lancaster Sound ice edge. The pre-disturbance control period lasted for a full five days providing adequate information on undisturbed whale behaviour, vocalizations, and distribution. The MV Arctic arrived at the ice edge on 24 June and the CCGS John A. MacDonald arrived two days later. The tracks of the ships through the study area are shown in Figure 3.

The originally planned study design involved the Arctic breaking its way into Nanisivik while the MacDonald simulated moderate levels of icebreaking ship traffic by operating for a few hours every two days at the ice edge. The study had to be re-designed in the field because the Arctic could not proceed in the heavy ice conditions. Thus, the MacDonald had to break the ice and lead the Arctic into Admiralty Inlet. However, because the ice was so heavy, the ships made very slow progress through Lancaster Sound. This coupled with the fact that both ships stopped every night created a series of disturbance periods and quiet intervals stretching over a period of five days after the MacDonald arrived at the ice edge. Behavioural observations and acoustic recordings were made throughout this period.

The subsequent post-disturbance period featured high levels of whale hunting by Inuit from Arctic Bay and the formation of major leads and cracks in the Lancaster Sound ice sheet.


86°
84°
82°
80°
DEVON
ISLAND
CAPE WARRENDER
JOHN A. MACDONALD
LANCASTER
SOUND
M.V. ARCTIC
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Adams I.
Wollaston Is.
CAPE CRAUFORD
CAPE CHARLES YORKE
CAPE JOY
CAPE HAY
ADMIRALTY
INLET
BYLOT
ISLAND
NAVY
BOARD
INLET
20
0
20
40
60
km
ARCTIC BAY
NANISIVIK
73°
73°
86°
84°
82°
80°

Fig. 3. The 1983 study area in late June. Observation/recording stations (occupied from 19-27 June) are indicated by solid triangles and a diamond. The shear zone and the route of the ships MV *Arctic* and CCGS *John A. MacDonald* are shown as dashed and dotted lines, respectively.

A dedicated helicopter was available to the project in 1983 allowing 18 surveys of the Lancaster Sound ice edge to be performed. Unfortunately, the Arctic arrived at the ice edge during a snow storm that prevented aerial surveys on that day.

1984

The 1984 study was a brief (one week) aerial survey effort to provide better coverage of the distributional responses of belugas and narwhals to the first arriving ship at the Lancaster Sound ice edge. In addition, we were able to obtain information on the responses of whales offshore from the ice edge. The 1984 study also provided information with which to assess whether whale responses were qualitatively similar over the three years of study.

Seven aerial surveys were flown; the first was on the day before the Arctic and the Louis St. Laurent arrived at the ice edge. The next four surveys were flown during the period when levels of ship activity were high. The final two surveys were flown after the ships had moved west into the ice but were probably still audible to whales at the ice edge.

RESULTS AND DISCUSSION

Ambient Noise

The underwater environment in the sea tends to be naturally quite noisy. A large number of measurements (each 10 min in length) of this ambient noise were made at the Admiralty Inlet ice edge in late June 1982 and at the Lancaster Sound ice edge in late June and early July 1983. These measurements document the natural noise levels that the whales experience in the absence of ship noise.

Ambient noise along the two ice edges was dominated by marine mammal vocalizations, particularly bearded seals, belugas and narwhals. Figure 4 illustrates typical ambient noise at the Lancaster Sound ice edge on 20 June 1983. The spectra in this figure show the noise levels at each frequency

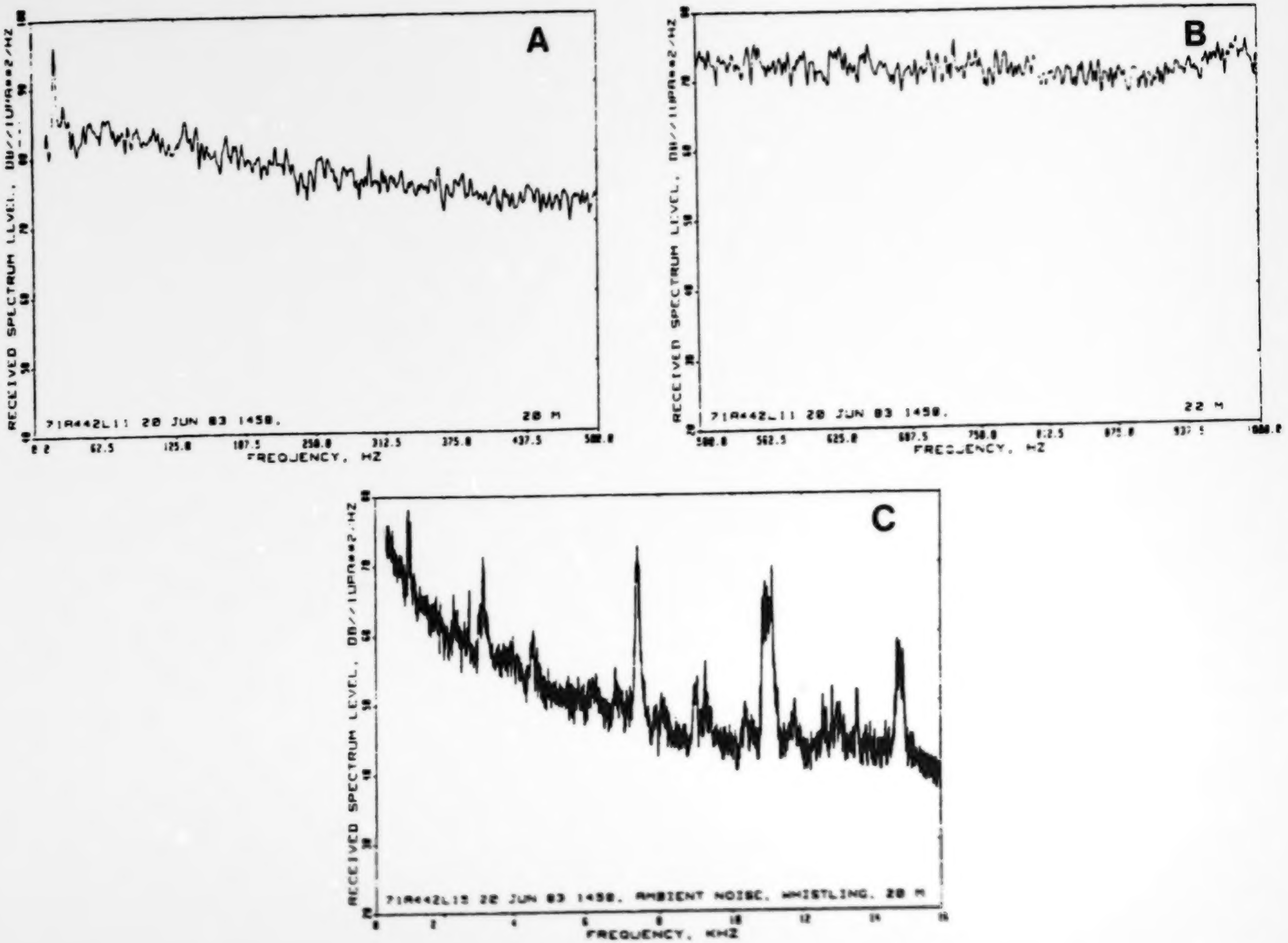


Fig. 4. Ambient noise spectra at the Lancaster Sound ice edge, 14:58, 20 June 1983; 20 m depth. Beluga vocalizations appear between 1 and 15 kHz.

from about 10 Hz to 16 kHz. The spikes in the higher frequency range (1-15 kHz--Fig. 4C) are from beluga calls. The low frequency peak at 19 Hz (Fig. 4A) is caused by ice cracking.

Figure 5 presents the spectra for ambient noise at the Lancaster Sound ice edge under much different conditions. This sample is from calm conditions in the middle of the 'night' (00:05 on 23 June). In general, the ambient levels are about 20 dB lower than in Figure 4, which is representative of the high end of the range of ambient noise. The peaks between 400 and 600 Hz in the spectra in Figure 5 represent a bearded seal call. Again, the low frequency peak is probably caused by ice under pressure.

Apart from the major temporal variations in ambient noise noted above, there were also differences among areas and habitats. The ambient levels at the Admiralty Inlet ice edge in 1982 ranged from 8 to 15 dB lower on average than the levels at the Lancaster Sound ice edge in 1983. This was a function of the generally calmer conditions that prevailed in 1982 and the fact that fewer animals were present in Admiralty Inlet.

Ambient noise was lower under the fast ice away from the edge than at the edge, where wave noise and animal calls were prominent. Paired measurements showed that ambient levels were up to 10 dB lower under the ice 11 km from the Lancaster Sound ice edge than were levels at the edge. Similar results were obtained by Thiele (1984) in a related study in 1983 that measured ambient levels at the Lancaster Sound ice edge and at a station under the ice about 30 km from the edge.

Ship Noise

Detailed studies of the source noise levels of the ships involved in this study were not part of the objectives of this phase of the study. Source noise levels and transmission loss were examined in related studies by Greene (1984) and Thiele (1984). The present study was primarily interested in the levels and spectral characteristics of ship noise that were actually heard by the whales that we were studying. The details of these received

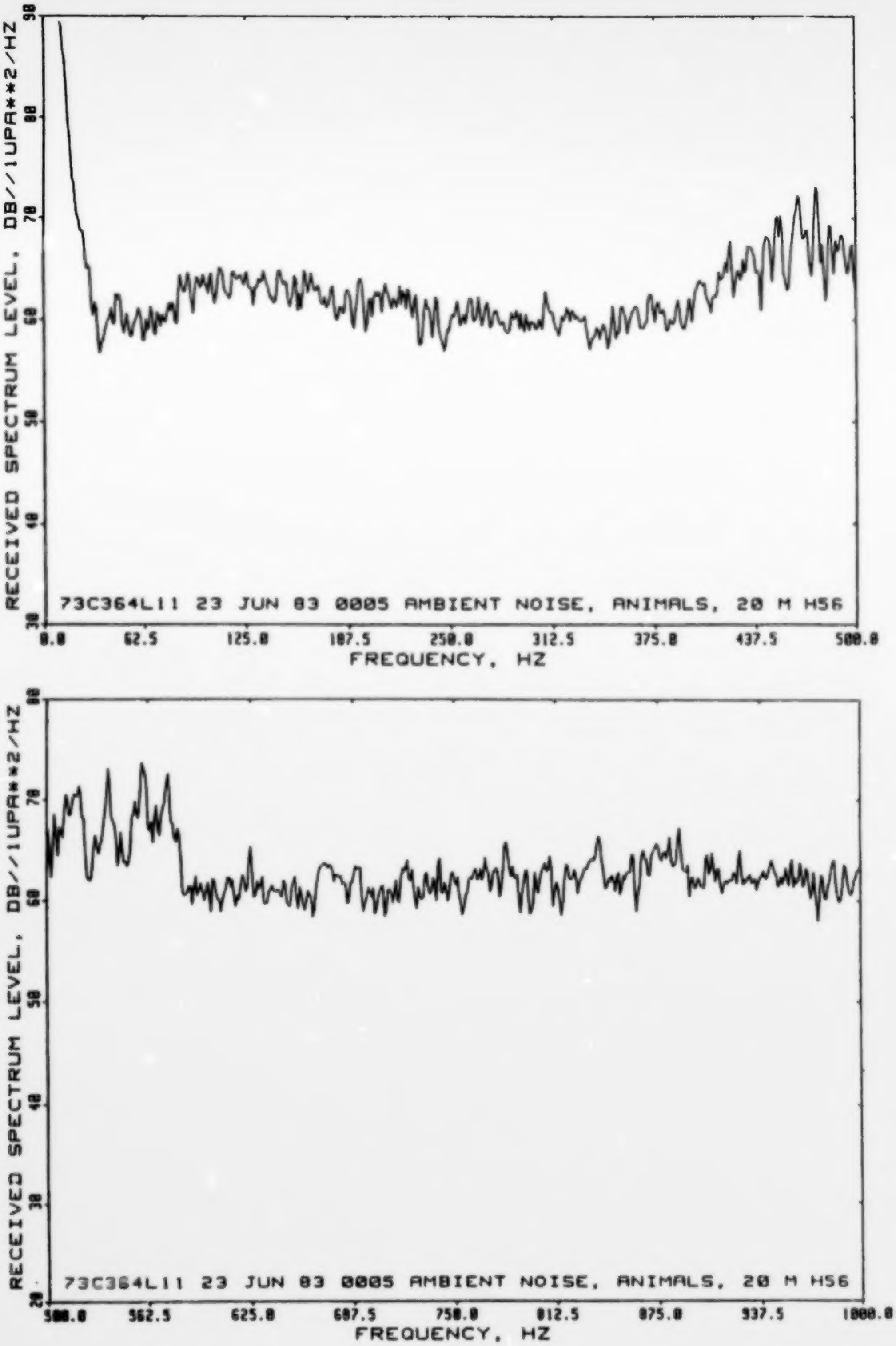


Fig. 5. Ambient noise spectra at the Lancaster Sound ice edge, 00:05, 23 June 1983; 20 m depth.

noise levels are presented in the background reports and are not repeated here. A few salient points, however, are reviewed here.

Firstly, the three ships involved in the present study are not unusually noisy ships (N. Brown; Bolt, Beranek and Newman Inc.; pers. comm.). Noise levels were fairly typical of other large ships. Thus, the reactions by whales (see below) were probably not a result of some unusual characteristics of the ships in question.

In both 1982 and 1983, the MV Arctic was the first ship to approach the ice edge hydrophones. Underwater noise from the ship was first detectable when the ship was at a considerable distance from the edge. In 1982, a tone (205 Hz) was first evident on the recorded spectra when the ship was 105 km away, although the tone was not audible to the human ear. The ship was plainly audible on the hydrophones at a distance of 46 km. In 1983, indications of tones were present on the spectra when the ship was 132 km away. The ship was distinctly, though faintly, audible on the hydrophone at a distance of 84 km. In fact, as will be discussed later, belugas began to emit 'alarm calls' at this time.

One of the more interesting findings of the present study is the prominence and potential importance of tonal sounds from the MV Arctic. In recent regulatory reviews (Arctic Pilot Project, Beaufort Sea Development) of the potential effects of ship noise on marine mammals, the emphasis has been placed on the low frequency (<50 to 100 Hz), broadband noise associated with propeller cavitation. The present study suggests that tonals associated with shipboard machinery may also be important. In both years, it was tonals that were first detectable on the sound spectra. These were not the very low frequency blade rate tonals associated with the rotation rate of the propeller but were tones with higher frequencies that might be detected by animals. The most prominent tones from the Arctic were at 53, 106 and 205 Hz. The first two were associated with the piston firing rate of the main engine (the fundamental and second harmonic). The 205 Hz tone came from the compressor used for the bubbler system that functions to reduce friction between the ship's hull and sea ice. The source level of the 205 Hz tone was estimated to be 171.4 dB//1 µPa at 1 m. The source level of the 53 Hz tone was estimated at 171.5 dB//1 μPa at 1 m. The estimated source level spectra of MV Arctic going ahead is shown in Figure 6.

The final point of interest is that ship noise was highly variable when the ships were operating in heavy ice as opposed to the much steadier sounds in open water. The typical ice-breaking pattern involved a forward ramming of the ice until momentum was lost. The ship would then go astern prior to taking another run at the ice. For the MV Arctic, noises going astern had different spectral characteristics and were about 5 dB higher than when going forward. Between these two modes, there was a lull in the noise and a very loud transition noise as the pitch of the propeller was changed from reverse to forward. Thus, there were major changes in ship noise during this cycle, although the cycle was repeated in a predictable manner.

Observed Behaviour Patterns of Narwhals and Belugas

Before presenting a year by year review of the principal findings of this study, we present a brief summary of the activity patterns of narwhals and belugas in undisturbed conditions and in response to ships.

Distribution and Movements

In all three years of study, the distribution and numbers of narwhals and belugas were strongly influenced by the occurrence of an ice barrier across Lancaster Sound. Typically, in such years, large numbers of belugas accumulate along the ice edge, awaiting access to their summering grounds located farther west. They distribute themselves more or less evenly along the Lancaster Sound ice edge. Large concentrations of belugas also occur along the south coast of Devon Island, the primary migration corridor in spring and in fall. Smaller numbers occur along the southern side of Lancaster Sound. Movements of belugas along the ice edge represent back and forth meanderings although, at any particular time, overall movements may be coordinated in one direction. Rates of casual, directed movement are in the order of 6-7 km/h.

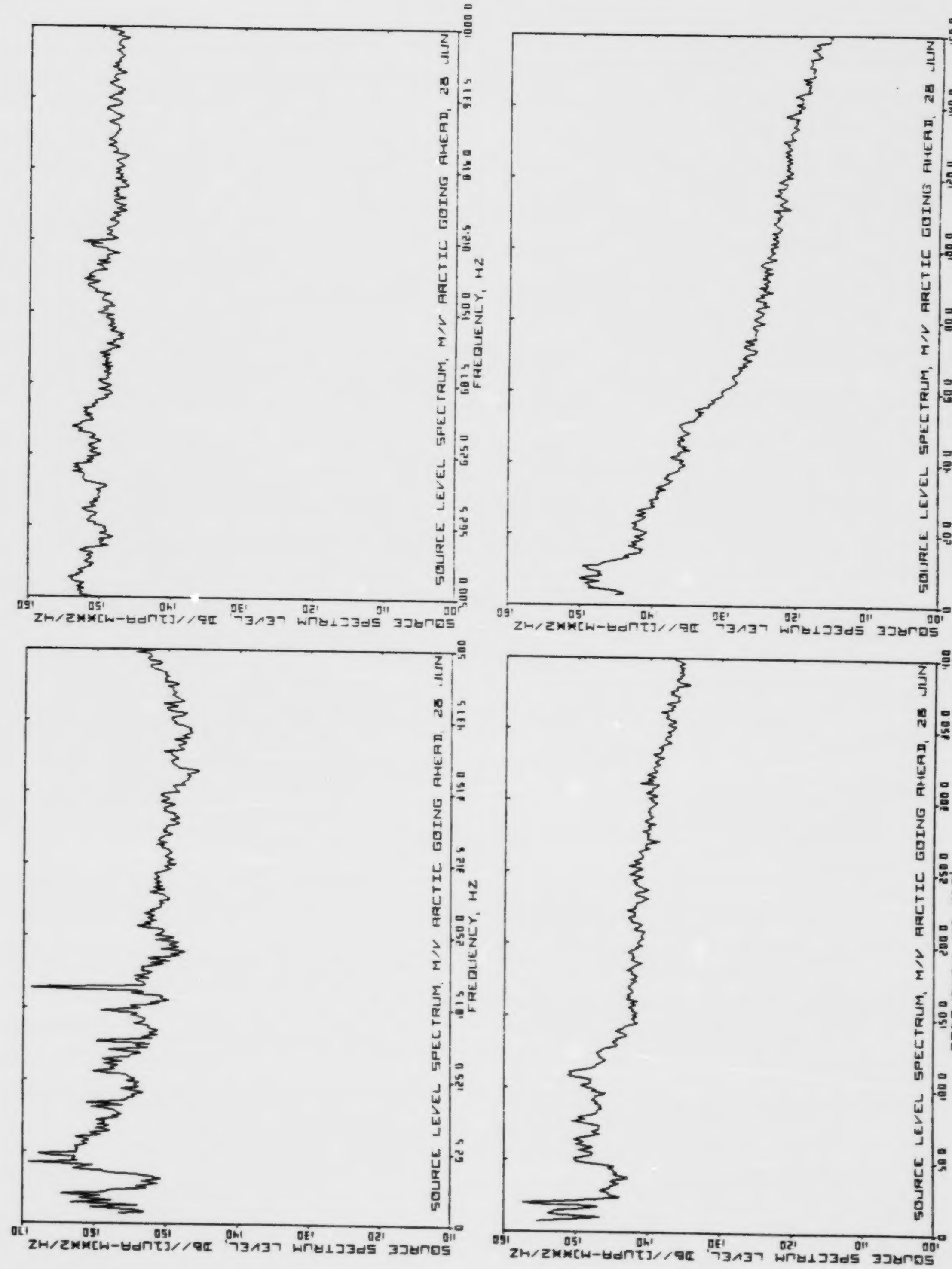


Fig. 6. Source level spectrum of the MV Arctic going ahead.

In mid to late June, narwhals also occur along ice edges in Lancaster Sound but in smaller numbers than belugas. Most of the narwhal population remains widely distributed in offshore waters at this time. That part of the population (primarily adult males) that is found along ice edges usually occurs along the southern half of the Lancaster Sound ice edge and along the adjacent ice edges of Navy Board and Admiralty inlets. Movements of narwhals along ice edges are generally back and forth and, like the beluga, their movements tend to be coordinated in one direction at any particular time. However, their movements appear to be less strongly directed than those of belugas; they often engage in circling and diving activity or they may rest close to the ice edge.

Ship approaches cause rapid movement of belugas along ice edges. This often results in clumped distribution patterns with major concentrations occurring in coastal areas adjacent to ice edges and large gaps in distribution along the ice edge in the direct path of the ship. Ship approaches also cause displacement of narwhals but not to the same degree as belugas.

Surface Activity Patterns

Belugas and narwhals along ice edges exhibit very different surface behaviour patterns in response to the approach of ships. We refer to these behaviours as the 'flee' response of the beluga and the 'freeze' response of the narwhal, although ultimately the outcome of the surface activities manifests itself in displacement of both species from the disturbance area.

Typically, the 'flee' response of the beluga is evident in their rapid movement along ice edges away from the approaching vessel. They may achieve speeds in excess of 20 km/h. During such movements, they rise unusually high out of the water ('porpoising') and undertake long shallow dives, close to or beneath the ice edge. At all times they remain close to or beneath the ice edge. The rapid 'fleeing' movements by belugas are highly coordinated in one direction over long segments of the ice edge; dense herds sometimes form at the 'tail end' of these movements. Pod integrity is lost (or becomes less obvious) in 'fleeing' movements and diving appears asynchronous. These notable surface activities of 'fleeing' belugas are associated with underwater emissions of 'alarm' calls (see below).

By contrast, the surface activity of narwhals in response to approaching ships is one of slow movements or lying motionless close to the ice edge. Rather than actually diving, they tend to sink during submergence. Often they huddle tightly in pods and may engage in physical contact. The movements of pods or individuals appear to be conducted independently of one another and grouping of pods into herds does not occur. The initial response of narwhals to ship approach is to associate strongly with the ice edge and with movements usually under the ice. Later, narwhals appear to disperse along the ice edge or offshore during ship disturbance. The 'freeze' behaviour of narwhals is associated with the cessation of their normal underwater sounds during their initial responses to ship disturbance (see below).

Vocal Behaviour

In June, the underwater environment at ice edges in Lancaster Sound is usually saturated with the vocalizations of narwhals, belugas and bearded seals. The presence of narwhals is evident by their dense click 'clatter' in the 3 to 6 kHz band and by discrete pulsed calls (generally 2-3 kHz) that fall primarily below the 'clatter' band. Ship approaches cause narwhals to temporarily cease vocalizing as part of their 'freeze' response.

Belugas are most evident in underwater recordings by their complex repertoire of tonal vocalizations that fall primarily in the frequency range between 2 and 8 kHz. In response to ship disturbances, their vocal activity changes notably to include more pulsed sounds, particularly broadband screams, and a variety of 'excited' tonal calls. We have designated these pulsive, broadband screams as 'alarm' calls in this study. Alarm-type signals appear to grade from first-order alarm signals such as screams to downswept tonals to calls (e.g. buzzes, chirp trains) suggestive of a level of 'excitedness'.

Whale Responses in 1982

Interpretation of the 1982 results was hindered because we were unable to fully document the normal patterns of distribution and behaviour of whales along the Admiralty Inlet ice edge prior to the arrival of the MV Arctic and because aerial surveys could not be conducted at the most appropriate times. Substantial responses to the ship were documented.

The approach of the Arctic to the Admiralty Inlet ice edge on 28 June evoked typical 'freeze' and 'flee' responses, respectively, in narwhals and belugas, and caused displacement of whales along and away from the ice edge. Strong avoidance reactions were undertaken by the belugas when the ship was still 35-40 km away but approaching fast (27 km/h). Just prior to their observed 'fleeing' movement, the ship was clearly audible on the hydrophones. The ship was also evident at lower frequencies in the noise spectra with a notable (80 dB//1 μPa) tonal peak at 205 Hz. The 'fleeing' movements of the belugas were accompanied by the pulsed scream 'alarm calls'. The bulk of the beluga movement (200-300 animals) passed by the ice-based observers over 1 h prior to the ship's arrival at the ice edge. As the ship approached within 12 km of the edge, movements of belugas appeared to become confused, with animals moving in both directions, frequently turning, milling and diving beneath the ice edge. In contrast to the behaviour of belugas, several narwhals remained close to the ice edge (exhibiting a 'freeze' behaviour) for long periods as the Arctic approached the ice edge. Narwhals were the last whales to leave the ice edge in front of the ship's path; a few individuals still remained within 5 km of the ship as it struck and entered the ice edge. Narwhals ceased vocalizing as the ship approached.

Narwhals and belugas were not seen at the Admiralty Inlet ice edge for over 30 h following the arrival of the Arctic. During this period the ship broke ice nearly continuously. By 30 h after its arrival at the ice edge, the Arctic had moved 28 km into the fast ice.

It is not certain how far belugas and narwhals were displaced from the Admiralty Inlet ice edge following the arrival of the Arctic but an aerial survey conducted 30 h later showed that there were no whales remaining along this edge. Large numbers of belugas were found along the adjacent coastal area (Fig. 7A) and many were moving back toward the Admiralty Inlet ice edge.

Within 48 h of the arrival of the Arctic, both narwhals and belugas had resumed normal activities along the Admiralty Inlet ice edge. The Arctic was over 45 km from the ice edge but still audible (100 dB//1 μPa in the 20-1000 Hz band) when both species were engaged in a feeding frenzy along the ice edge. The distribution of whales 52 h after the arrival of the Arctic is shown in Figure 7B. This figure also gives an indication of some avoidance of the stopped icebreaker along the Lancaster Sound ice edge.

Whale Responses in 1983

Although we were unable to conduct strictly controlled disturbance experiments in 1983, ship activity occurred on an intermittent periodic basis, permitting observations of the reactions of narwhals and belugas to ship sounds at discrete intervals following quiet periods. A total of seven 'disturbance' periods were recognized but these graded in intensity from ship approaches to the ice edges during the first two disturbances to subsequent start-ups and ice-breaking operations as the ships moved away from the ice edge during the remaining disturbance periods. By the seventh disturbance period, the ships were over 40 km from the ice edge.

Pre-Disturbance

Aerial surveys were conducted on five different days prior to the arrival of the MV Arctic at the Lancaster Sound ice edge in June 1983. The surveys showed that belugas (maximum of 939 on 23 June) were more or less evenly distributed along the entire Lancaster Sound ice edge. Narwhals were consistently found along the southern third of the ice edge where a maximum of 115 were counted on 21 June. Both species of whales associated strongly with the ice edge; the majority were found within 400 m of the ice edge and their movements were parallel to the ice edge.

The ice edge populations of narwhals and belugas contained a preponderance of adult males. Over 90% of the narwhals along the ice edge were adult males. At least 61% of the adult population of belugas were

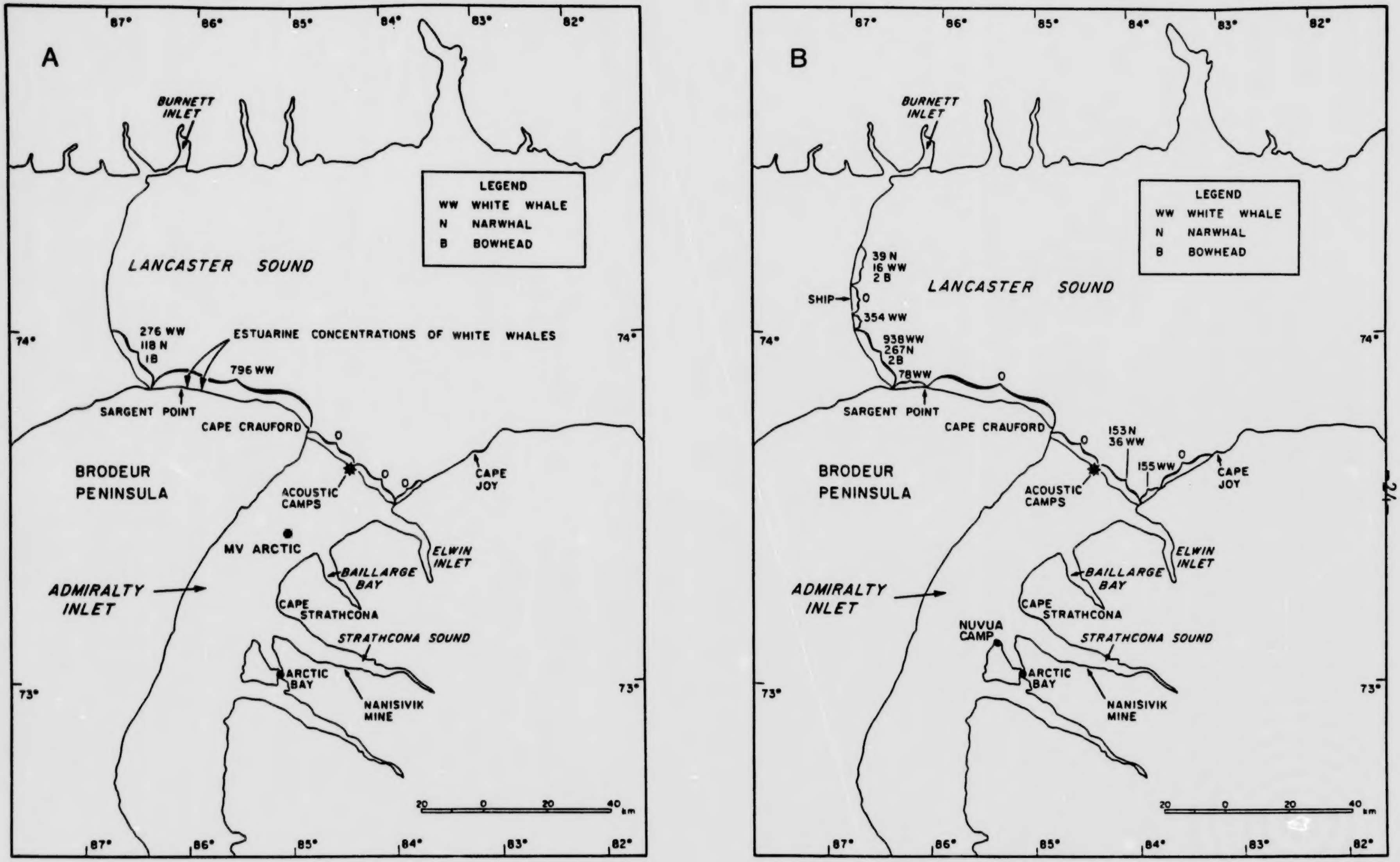

A
87°
86°
85°
84°
83°
82°
74°
73°
BURNETT INLET
LEGEND
WW WHITE WHALE
N NARWHAL
B BOWHEAD
LANCASTER SOUND
276 WW
118 N
1B
ESTUARINE CONCENTRATIONS OF WHITE WHALES
796 WW
SARGENT POINT
CAPE CRAUFORD
BRODEUR PENINSULA
ACOUSTIC CAMPS
CAPE JOY
MV ARCTIC
ELWIN INLET
BAILLARGE BAY
ADMIRALTY INLET
CAPE STRATHCONA
STRATHCONA SOUND
ARCTIC BAY
NANISIVIK MINE
20
0
20
40
km
B
39 N
16 WW
2 B
SHIP
354 WW
938WW
267N
2B
78WW
153N
36 WW
155WW
NUVUA CAMP

Fig. 7. Distribution and numbers of narwhals, white whales (belugas) and bowhead whales along the Admiralty Inlet ice edge, adjacent coastal areas and part of the Lancaster Sound ice edge (A) between 20:51 and 22:05, 29 June 1982 and (B) 20:30 and 22:07, 30 June 1982. The position of the icebreaker John A. MacDonald is also shown along the Lancaster Sound ice edge on 30 June.

thought to be males (i.e. either in distinctive 'bachelor' pods or adults not accompanied by immatures).

Approach of MV Arctic

The first evident behavioural changes in whale behaviour in response to the MV Arctic were noted at 08:00 on 24 June when the ship was about 84 km from the Lancaster Sound ice edge. The ship was faintly audible to the human ear from the hydrophone output and the vocal activity (several broadband screams and downswept tonals) of belugas indicated that they were aware of the sound. The 'alarm calls' were also heard at a recording station on the fast ice 11 km from the ice edge. The clicking sounds of narwhals were present but intermittent at 08:00. Shortly afterward, belugas began moving rapidly along the ice edge and narwhals exhibited their 'freeze' behaviour. Belugas had left the area over 2 h before the Arctic reached the edge at 12:20. The last narwhals left the area about 40 min before the ship arrived.

Because of poor weather and unstable ice conditions, we were unable to determine how far the whales were displaced by the arrival of Arctic nor were we able to determine when they first returned to the disturbance area. The Arctic operated more or less continuously breaking ice after its arrival until 09:07 the next morning (25 June). An aerial survey on 25 June, 2 h after Arctic had ceased ice-breaking operations, showed that narwhals had already returned to the disturbance area; in fact they were concentrated near the bight in the ice created by the ship (Fig. 8A). Belugas appeared to be just arriving in the area and by late in the day, 10 h after the Arctic stopped, they appeared to have fully re-occupied the southern part of the Lancaster Sound ice edge (Fig. 8B).

Start-up of Arctic and Arrival of John A. MacDonald

Both species of whales had returned to normal behavioural patterns before the Arctic started-up and began ice-breaking at 07:56 on 26 June. The start-up caused an immediate 'fleeing' movement (accompanied by 'alarm calls') of belugas that had been in the area of the bight. Over 225 belugas passed by one observer within a period of 9 min. The few narwhals that had been in the area disappeared.

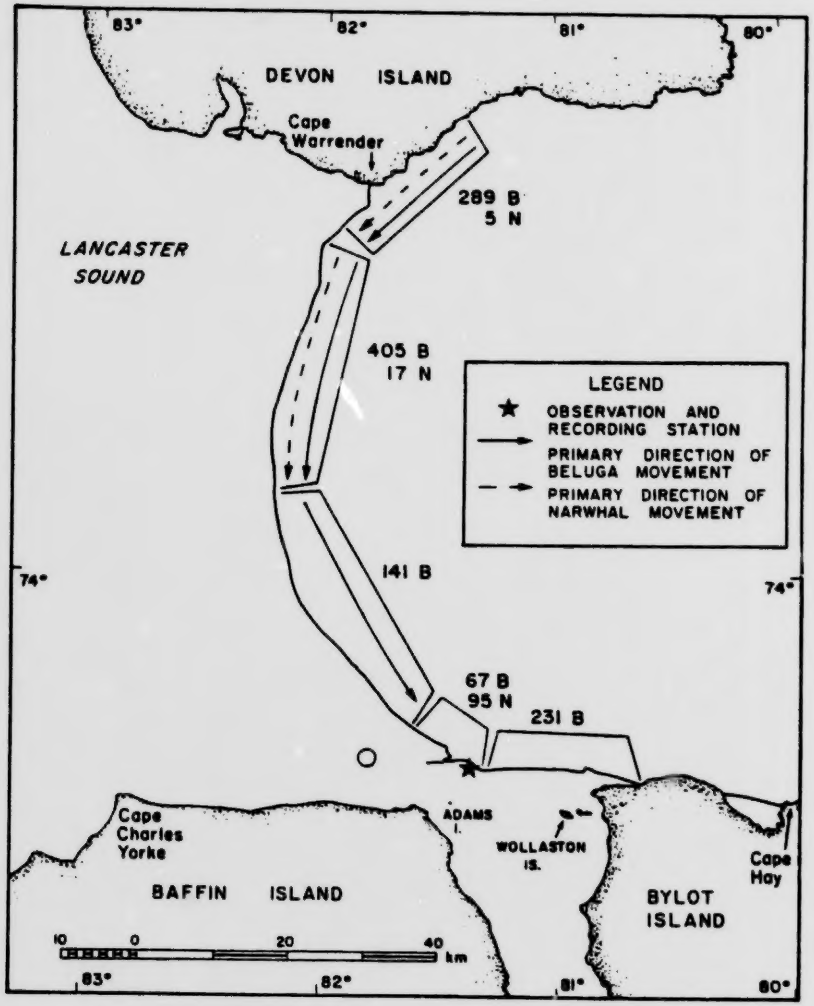

83°
82°
81°
80°
DEVON ISLAND
Cape Warrender
LANCASTER SOUND
289 B 5 N
405 B 17 N
141 B
67 B 95 N
231 B
LEGEND
★ OBSERVATION AND RECORDING STATION
PRIMARY DIRECTION OF BELUGA MOVEMENT
PRIMARY DIRECTION OF NARWHAL MOVEMENT
74°
Cape Charles Yorke
ADAMS I.
WOLLASTON IS.
BAFFIN ISLAND
BYLOT ISLAND
Cape Hay
10
0
20
40
km

Fig. 8A. Distribution and numbers of narwhals and belugas recorded during survey 6, 10:59-11:49, 25 June 1983. Totals of 117 narwhals and 1133 belugas were recorded. The position of the MV *Arctic* at the time of the survey is indicated by an open circle. Arrows indicate direction of movement when 75% or more of the whales were moving in the same direction in a particular ice-edge segment.

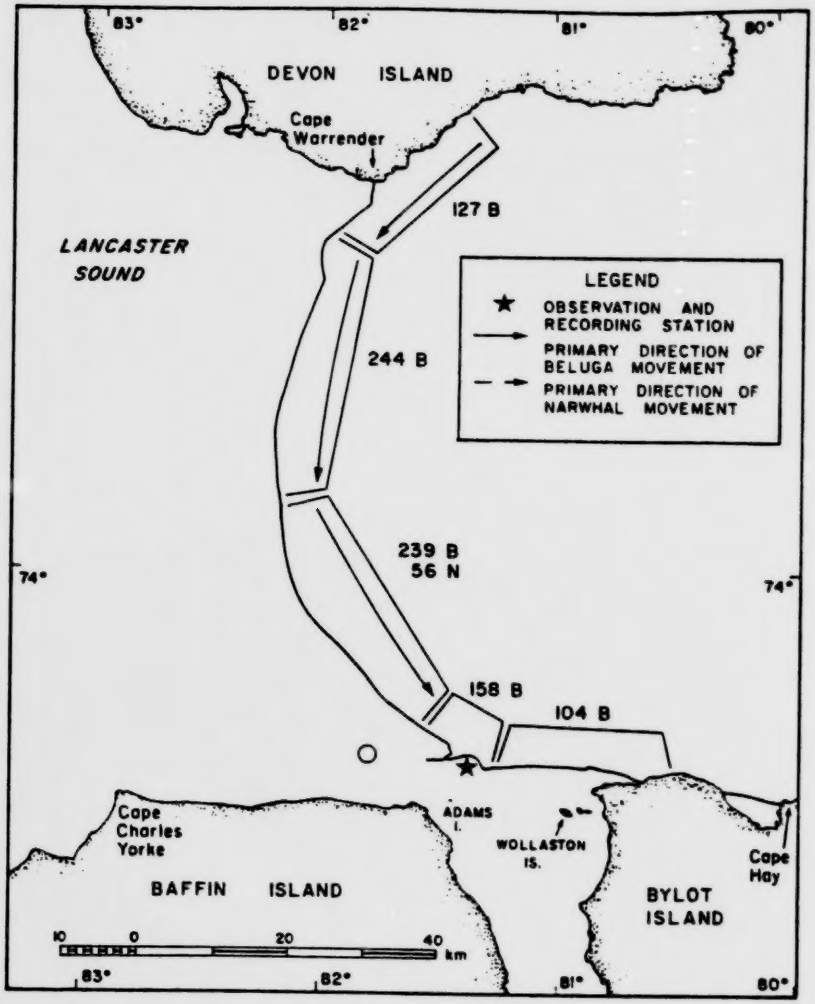

83°
82°
81°
80°
DEVON ISLAND
Cape Warrender
LANCASTER SOUND
127 B
244 B
239 B 56 N
158 B
104 B
LEGEND
★ OBSERVATION AND RECORDING STATION
PRIMARY DIRECTION OF BELUGA MOVEMENT
PRIMARY DIRECTION OF NARWHAL MOVEMENT
74°
Cape Charles Yorke
ADAMS I.
WOLLASTON IS.
BAFFIN ISLAND
BYLOT ISLAND
Cape Hay
10
0
20
40
km

Fig. 8B. Distribution and numbers of narwhals and belugas recorded during survey 7, 19:24-20:24, 25 June 1983. Totals of 56 narwhals and 872 belugas were recorded. The position of the MV *Arctic* at the time of the survey is indicated by an open circle.

An aerial survey conducted 1.5 h after the ship started-up showed that belugas had been displaced as much as 49 km north along the ice edge (Fig. 9A). Rough calculations indicate that they must have sustained speeds in excess of 20 km/h. Narwhals had also been displaced; none were within 18 km north of the ship track. Both narwhals and belugas ceased their movements south from the ship track when they reached the coast of Bylot Island about 20 km from the disturbance area. It is probable that the whales first reacted to the Arctic but, by the time of the survey, the approach of the MacDonald was also having an effect. The MacDonald arrived at the ice edge at about 13:30 on 26 June.

An aerial survey conducted 1 h after the arrival of the MacDonald showed that belugas had continued their northern movement along the ice edge; the closest animals were 80 km north of the ship track. The closest narwhals were 37 km north of the ship track and it was apparent that some narwhals had dispersed offshore (Fig. 9B). Large numbers of belugas were also concentrated along the coast of Bylot Island.

After their departure, belugas were not seen or heard throughout the second disturbance period. However, narwhals returned to the disturbance area within 12 h of the initial disturbance when the MacDonald was still breaking ice at a distance of 13 km. Maximum received noise levels at the time were in the order of 120 dB//1 μPa in the 20-1000 Hz band. The surface activity of the narwhals appeared normal and in the quieter moments between the ramming and backing phases of the ice-breaking ship, narwhal click 'clatter' was strong.

Subsequent Ship Start-ups

During the 5-day period beginning on 27 June, the MacDonald and the Arctic progressed slowly westward through the fast ice, averaging just over 4 km per day. The Arctic operated only intermittently, following the track of the MacDonald. Although noise levels diminished somewhat, they were not insignificant; maximum received noise levels at the ice edge still achieved 115 dB//1 μPa in the 20-1000 Hz band during backing operations of the MacDonald on 1 July.

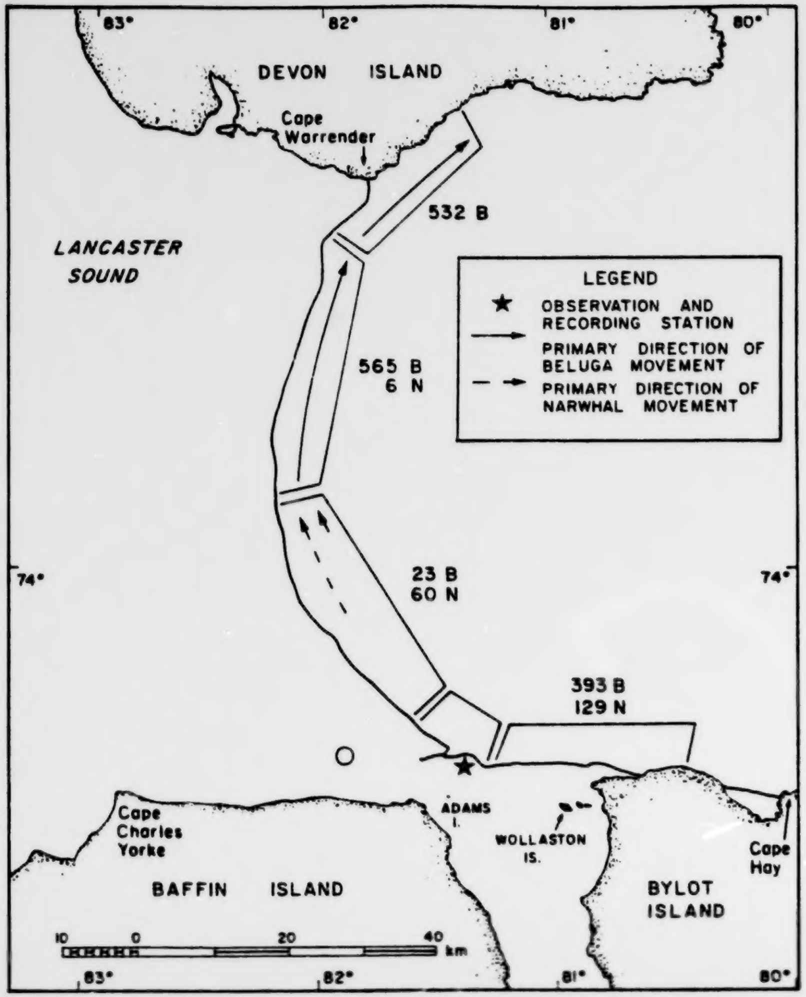

83°
82°
81°
80°
DEVON ISLAND
Cape Warrender
532 B
LANCASTER SOUND
LEGEND
★ OBSERVATION AND RECORDING STATION
PRIMARY DIRECTION OF BELUGA MOVEMENT
PRIMARY DIRECTION OF NARWHAL MOVEMENT
565 B
6 N
74°
23 B
60 N
74°
393 B
129 N
ADAMS I.
WOLLASTON IS.
Cape Charles Yorke
Cape Hoy
BAFFIN ISLAND
BYLOT ISLAND
10
0
20
40
km
83°
82°
81°
80°

Fig. 9A. Distribution and numbers of narwhals and belugas recorded during survey 8, 09:22-10:57, 26 June 1983. Totals of 195 narwhals and 1513 belugas were recorded. The position of the MV *Arctic* at the time of the survey is indicated by an open circle.

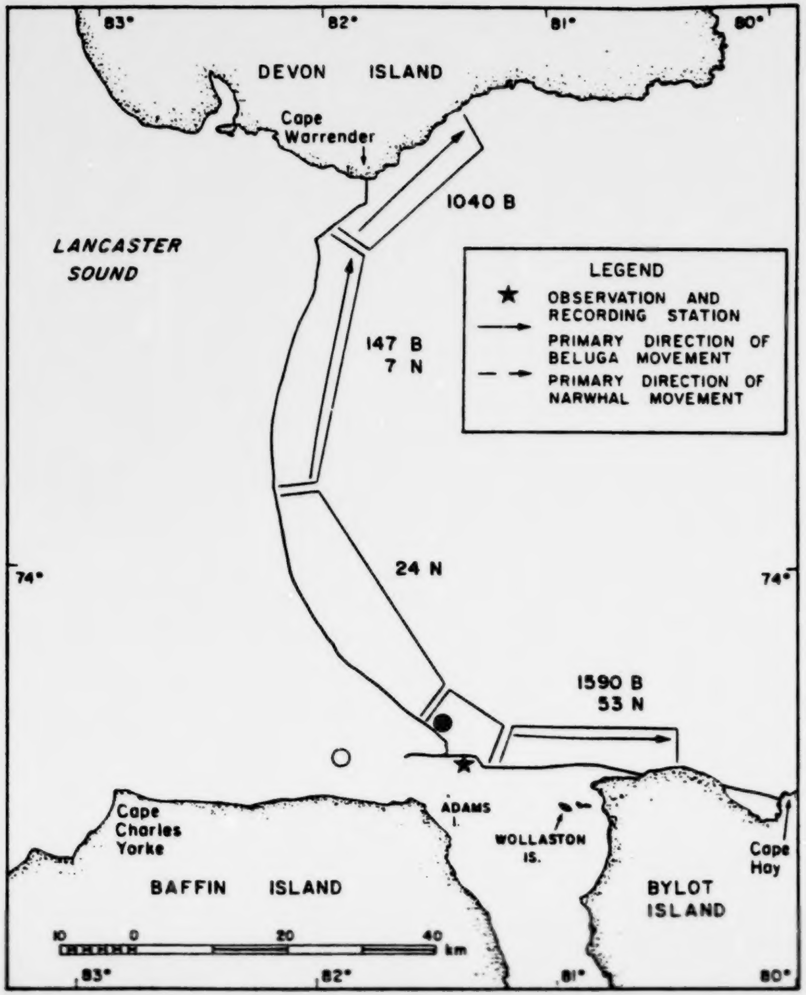

83°
82°
81°
80°
DEVON ISLAND
Cape Warrender
1040 B
LANCASTER SOUND
LEGEND
★ OBSERVATION AND RECORDING STATION
PRIMARY DIRECTION OF BELUGA MOVEMENT
PRIMARY DIRECTION OF NARWHAL MOVEMENT
147 B
7 N
74°
24 N
74°
1590 B
53 N
ADAMS I.
WOLLASTON IS.
Cape Charles Yorke
Cape Hoy
BAFFIN ISLAND
BYLOT ISLAND
10
0
20
40
km
83°
82°
81°
80°

Fig. 9B. Distribution and numbers of narwhals and belugas recorded during survey 9, 14:28-16:50, 26 June 1983. Totals of 84 narwhals and 2777 belugas were recorded. The position of the MV *Arctic* and CCGS *John A. MacDonald* at the time of the survey are indicated by open and solid circles, respectively.

Except for one instance when the MacDonald returned toward the ice edge on 29 June, we did not discern any notable influence of ship start-ups or operations on the behaviour of narwhals. In fact, initially, following the arrival of both ships, narwhals appeared to be attracted to the bight and the entrance to the rubble-filled ship track, and many engaged in deep dives directed toward the ship track. This 'exploratory' activity appeared to wane following their initial interest; smaller numbers of narwhals continued to appear sporadically around the ship track and most of their dives continued to be directed into the ship track. By the sixth disturbance period, on 30 June, most of the narwhals had moved to a feeding area along the ice edge north of the Wollaston Islands (Fig. 10). This 'feeding' aggregation in association with belugas was observed at the same location on 1 July. It was the only case of intensive feeding activity that we observed along the ice edge during the entire study period.

Belugas continued to show reactions to the ships during the start-ups and ice-breaking operations that constituted the third to seventh disturbance periods. They reacted with 'alarm calls' during the 3rd, 4th and 5th ship start-ups, and at other times, during ice-breaking operations, the vocal activity of belugas suggested a heightened level of excitedness. Belugas returned to the ship track area only during the quiet intervals following the 3rd and 4th disturbances; it was not until the fifth disturbance period that belugas actually returned to the ship track while the ships were operating. (They departed again when the MacDonald returned to within 18 km of the ice edge to assist Arctic.) Although aerial survey coverage was incomplete after 27 June, it appeared that belugas did not fully reoccupy the ice edge around the ship disturbance area until early July during the seventh disturbance period (Fig. 11A).

Ice Crack Formation

Beyond the seventh disturbance period (1 July), the patterns of distribution and behaviour of narwhals and belugas were complicated by ship-induced development of ice cracks and considerable disturbance by hunters. Nonetheless, some interesting aspects of the behaviour of these two species were documented.

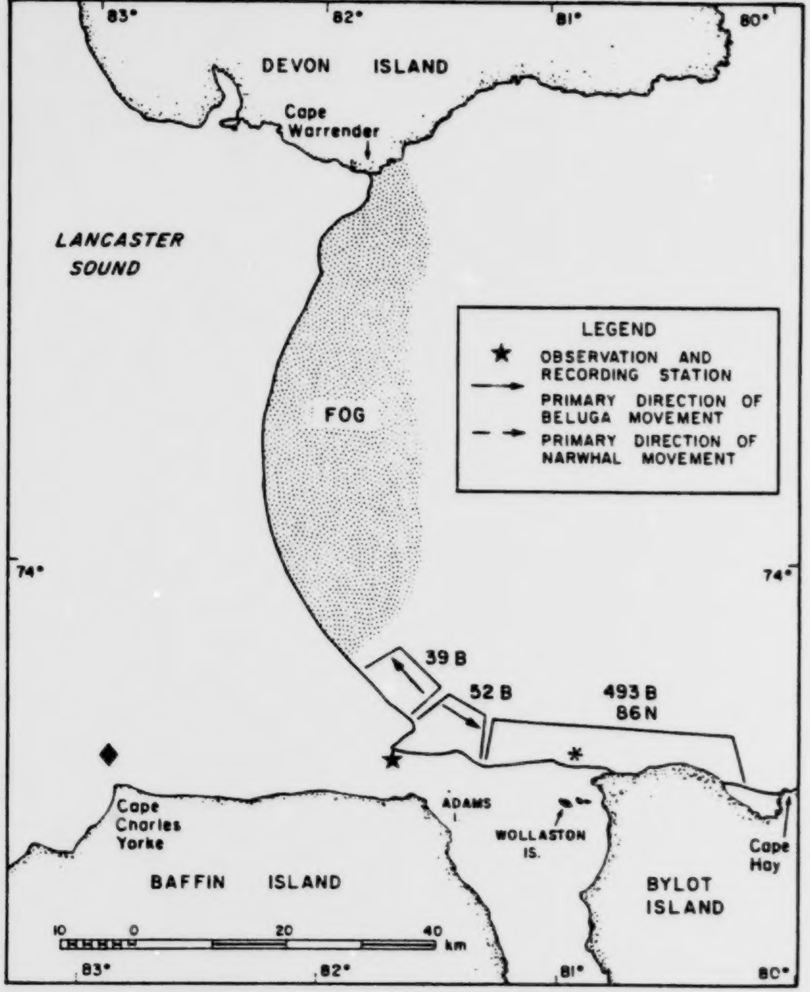

83°
82°
81°
80°
DEVON ISLAND
Cape Warrender
LANCASTER SOUND
FOG
LEGEND
★ OBSERVATION AND RECORDING STATION
→ PRIMARY DIRECTION OF BELUGA MOVEMENT
- - → PRIMARY DIRECTION OF NARWHAL MOVEMENT
74°
74°
39 B
52 B
493 B
86 N
Cape Charles Yorke
ADAMS I.
WOLLASTON IS.
BAFFIN ISLAND
BYLOT ISLAND
Cape Hay
10
0
20
40
km
83°
82°
81°
80°

Fig. 10A. Distribution and numbers of narwhals and belugas recorded during survey 12, 12:42-13:45, 30 June 1983. Totals of 86 narwhals and 584 belugas were recorded along the southern (fog-free) portion of the ice edge. The asterisk represents the location along the Navy Board Inlet ice edge of an aggregation of 55 narwhals and 396 belugas. The positions of the MV *Arctic* and CCGS *John A. MacDonald* at the time of the survey are indicated by a diamond.

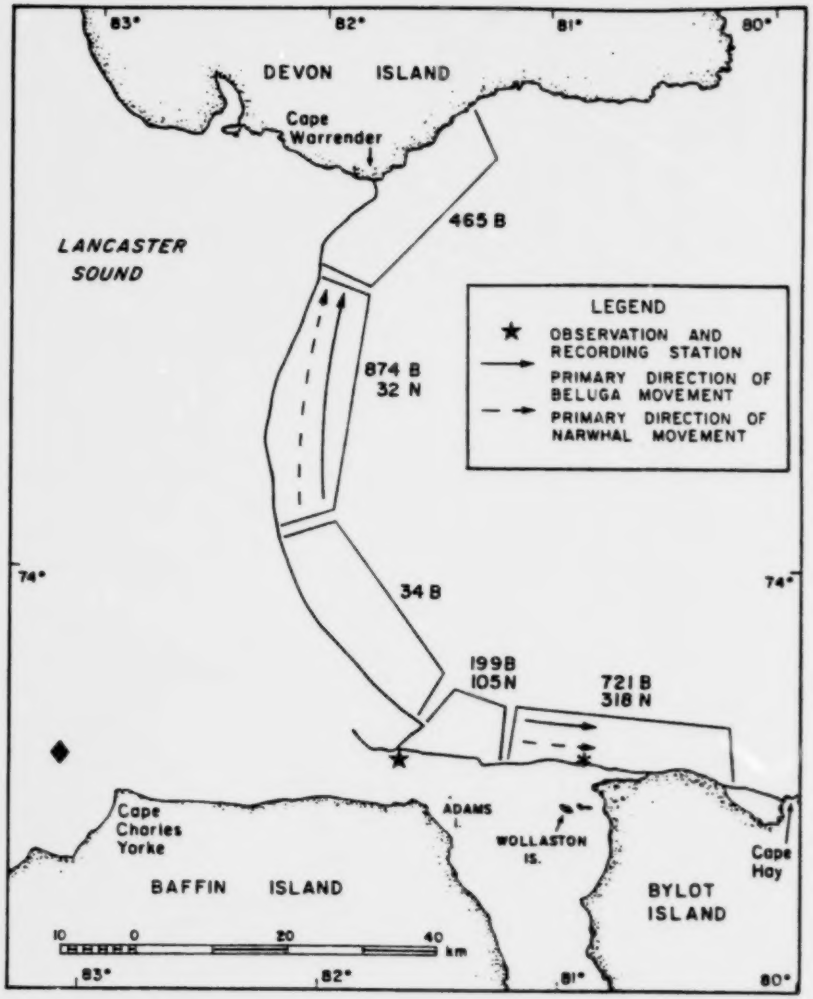

83°
82°
81°
80°
DEVON ISLAND
Cape Warrender
LANCASTER SOUND
465 B
LEGEND
★ OBSERVATION AND RECORDING STATION
→ PRIMARY DIRECTION OF BELUGA MOVEMENT
- - → PRIMARY DIRECTION OF NARWHAL MOVEMENT
874 B
32 N
74°
74°
34 B
199B
105N
721 B
318 N
Cape Charles Yorke
ADAMS I.
WOLLASTON IS.
BAFFIN ISLAND
BYLOT ISLAND
Cape Hay
10
0
20
40
km
83°
82°
81°
80°

Fig. 10B. Distribution and numbers of narwhals and belugas recorded during survey 13, 12:35-14:25, 1 July 1983. Totals of 455 narwhals and 2293 belugas were recorded. The asterisk represents the location along the Navy Board Inlet ice edge of an aggregation of 239 narwhals and 391 belugas. The positions of the MV *Arctic* and the CCGS *John A. MacDonald* at the time of the survey are indicated by a diamond.

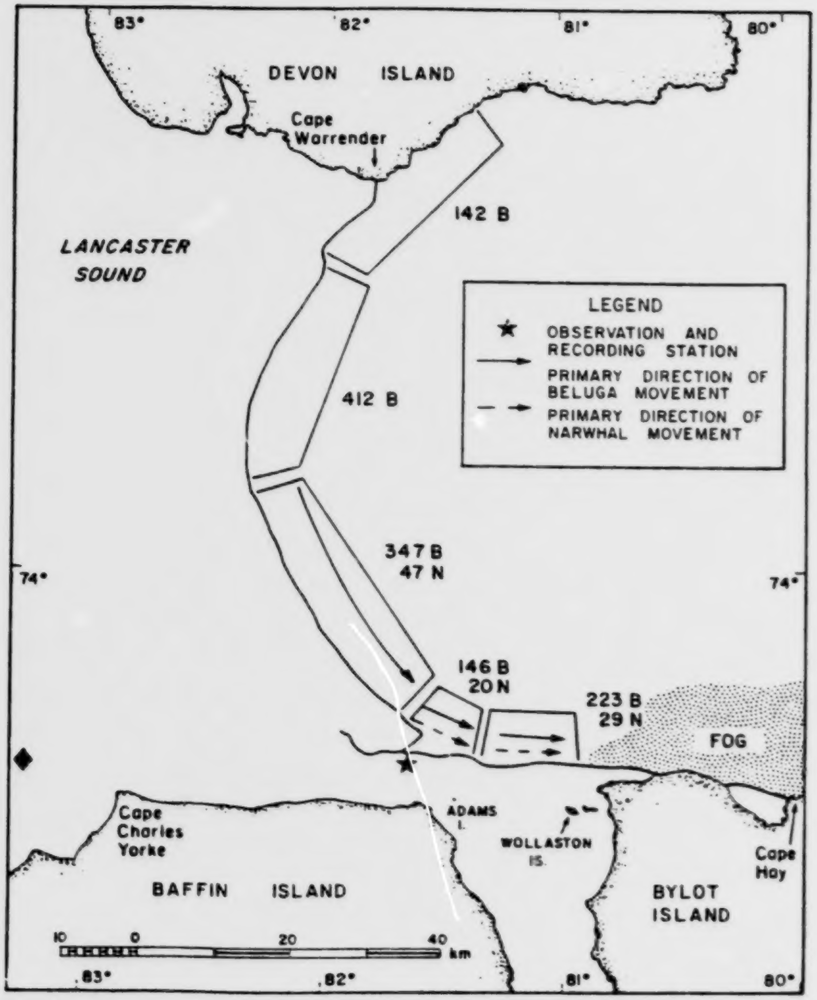

83°
82°
81°
80°
DEVON ISLAND
Cape Warrender
LANCASTER SOUND
142 B
412 B
347 B
47 N
146 B
20 N
223 B
29 N
FOG
LEGEND
★ OBSERVATION AND RECORDING STATION
PRIMARY DIRECTION OF BELUGA MOVEMENT
PRIMARY DIRECTION OF NARWHAL MOVEMENT
74°
74°
Cape Charles Yorke
ADAMS I.
WOLLASTON IS.
Cape Hay
BAFFIN ISLAND
BYLOT ISLAND
10
0
20
40
km
83°
82°
81°
80°

Fig. 11A. Distribution and numbers of narwhals and belugas recorded during survey 14, 11:17-12:28, 2 July 1983. Totals of 96 narwhals and 1270 belugas were recorded. Fog prevented a survey of the eastern portion of the Navy Board Inlet ice edge and the coast of Bylot Island. The positions of the MV *Arctic* and CCGS *John A. MacDonald* at the time of the survey are indicated by a diamond.

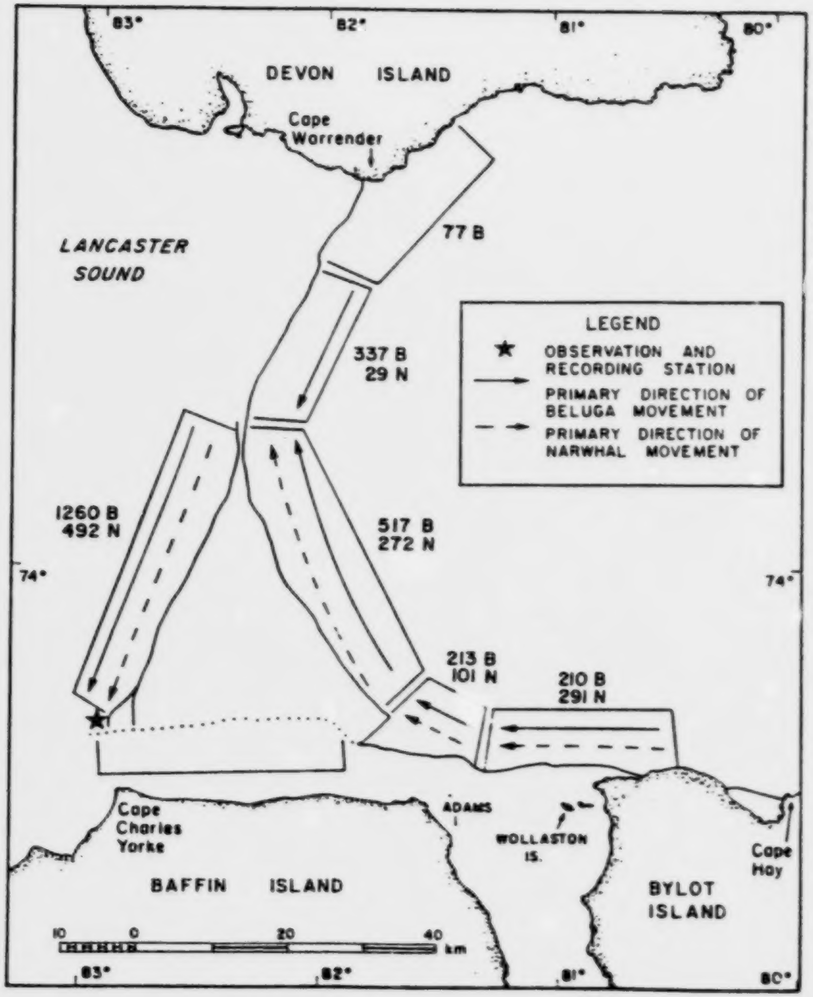

83°
82°
81°
80°
DEVON ISLAND
Cape Warrender
LANCASTER SOUND
77 B
337 B
29 N
1260 B
492 N
517 B
272 N
213 B
101 N
210 B
291 N
LEGEND
★ OBSERVATION AND RECORDING STATION
PRIMARY DIRECTION OF BELUGA MOVEMENT
PRIMARY DIRECTION OF NARWHAL MOVEMENT
74°
74°
Cape Charles Yorke
ADAMS I
WOLLASTON IS.
Cape Hay
BAFFIN ISLAND
BYLOT ISLAND
10
0
20
40
km
83°
82°
81°
80°

Fig. 11B. Distribution and numbers of narwhals and belugas recorded during survey 15, 10:55-12:45, 3 July 1983. Totals of 1185 narwhals and 2614 belugas were recorded.

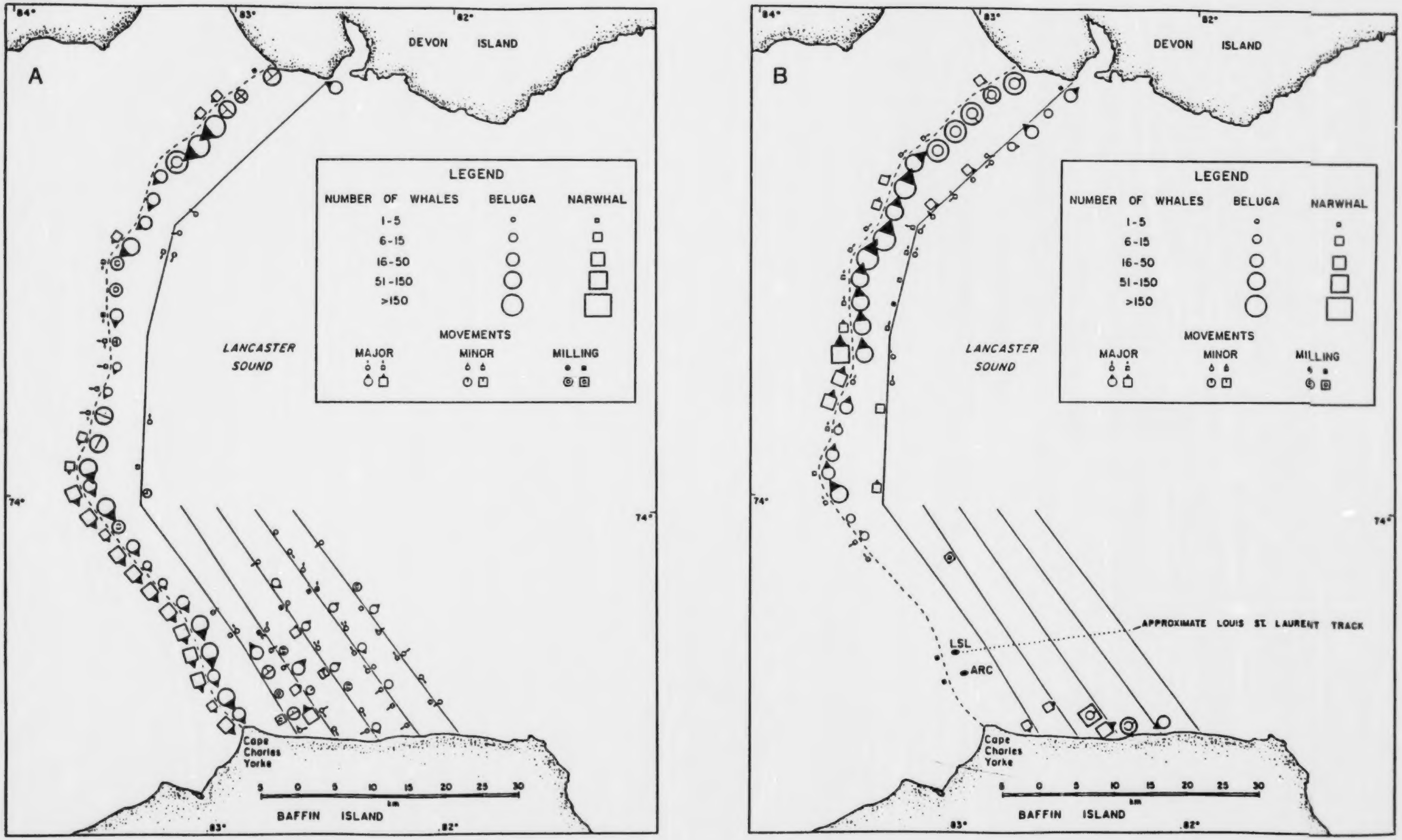
Very soon after the formation of a major crack in the fast ice on 2 July, there was a large influx of narwhals and belugas into the crack. The movement toward the ice crack appeared coordinated from over a large area, suggesting some form of information transfer--probably acoustic. For the first time in the study, many female and young narwhals were noted, presumably arriving from offshore areas. A total of 1752 whales (1260 belugas; 492 narwhals) were counted along the single long crack (Fig. 11B). The crack led directly toward the ice-breaking ships and both narwhals and belugas penetrated to within 23 km of the closest ship when they arrived at the end of the ice crack where it joined the ship track. In such a restrictive situation, the whales were highly vulnerable; hunters from Arctic Bay took 23 adult male narwhals between 3 and 8 July.

Whale Responses in 1984

We conducted a one week aerial survey program from 27 June to 2 July in 1984 to document the large scale responses of belugas and narwhals along the Lancaster Sound ice edge to the approach and icebreaking activities of the MV *Arctic* and CCGS *Louis St. Laurent*. No ice-based parties were present in 1984 so we have no data on received levels of ship noise or whale vocalizations.

An aerial survey on 27 June, the day before the ships arrived, documented typical pre-disturbance patterns of whale distribution (Fig. 12A). Belugas were distributed more or less evenly along the length of the ice edge and narwhals were evenly distributed along the southern half of the edge. Both species were widely distributed in small numbers on the offshore transects. The ships were over 300 km away at the time of the survey.

Major changes in whale distribution were occurring when we conducted the next survey on the morning of 28 June (Fig. 12B). We began the survey at 08:00, 2 h after the *Arctic* arrived at the ice edge and stopped its main engine. The *Louis St. Laurent* was approaching the ice edge; it arrived at 09:00. Virtually all of the whales had vacated the offshore waters near the tracks of the approaching vessels. Along the ice edge, no belugas and only four narwhals were found along a 27 km stretch of the edge centred in the position of the *Arctic*. The narwhals were exhibiting their 'freeze'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LEGEND
NUMBER OF WHALES
BELUGA
NARWHAL
1-5
6-15
16-50
51-150
>150
MOVEMENTS
MAJOR
MINOR
MILLING
5 0 5 10 15 20 25 30
km
LSL
ARC
APPROXIMATE LOUIS ST. LAURENT TRACK

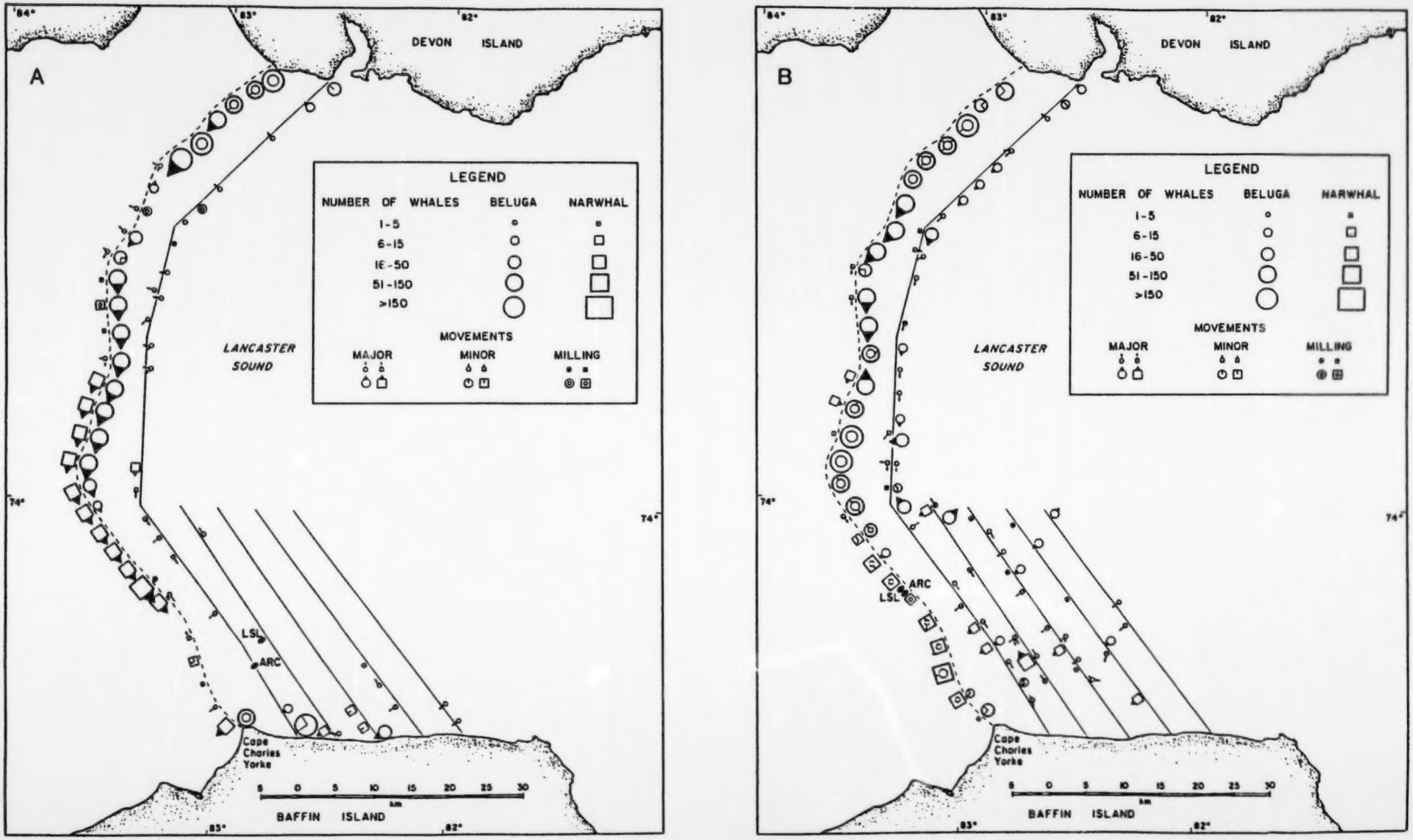
Fig. 12. Distribution and directions of movement of narwhals and belugas recorded during aerial surveys on (A) 27 June 1984 (11:30-14:15) and (B) 28 June 1984 (08:00-10:00). The positions of the MV Arctic (ARC) and CCGS Louis St. Laurent (LSL) at the time of the survey are also indicated.

behaviour close to the ice edge. The large majority of belugas and narwhals were swimming north along the ice edge away from the ships. No belugas were present within 20 km of the ship. Animals from 20-80 km north of the ships were moving strongly north. Whales over 80 km north of the ships were milling and resting and were apparently not reacting to the ships. Thus, some belugas had moved at least 20 km from the ships and others were reacting at distances of up to 80 km. The bulk of the narwhals along the edge had also moved similar distances.

By 16:00 on 28 June, 9 h after the St. Laurent arrived at the ice edge, whales had begun to return to the area (Fig. 13A). The ships had been drifting since their arrival with their main engines off but some shipboard machinery was operating. Narwhals had advanced substantially farther south (15 km) than had belugas but both species were moving back into the previously disturbed area.

During the night, the two ships moved into the ice a short distance and again stopped. The aerial survey on the morning of 29 June showed that narwhal distribution had returned to the pre-disturbance normal condition 24 h after the arrival of the ships (Fig. 13B). Similarly, the offshore distribution of narwhals and belugas had returned to normal. However, the distribution of belugas along the ice edge was still affected by the ships. Belugas had re-occupied the edge north of the ships but were milling and circling and had not passed the ships to re-occupy the southern portion of the edge (Fig. 13B).

One additional disturbance episode was documented in 1984. In the early evening of 29 June, both ships started up and moved south along the ice edge and then turned west into the ice and began icebreaking operations. We were surveying the easternmost transect line (20-25 km from ice edge) when the ships started moving. The reactions of the whales was immediate and striking. Virtually all of the whales began moving very rapidly, exhibiting porpoising behaviour and spending very little time underwater. The 'fleeing' behaviour of the belugas was faster than the narwhals but even the latter species was moving faster than previously observed. Along the ice edge one hour later, narwhals and belugas were streaming north away from the ships.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NUMBER OF WHALES
BELUGA
NARWHAL
1-5
6-15
16-50
51-150
>150
MOVEMENTS
MAJOR
MINOR
MILLING
5 0 5 10 15 20 25 30
km

Fig. 13. Distribution and directions of movement of narwhals and belugas recorded during aerial surveys on (A) 28 June 1984 (16:00-18:00) and (B) 29 June (08:10-10:15). The positions of the MV Arctic (ARC) and CCGS Louis St. Laurent (LSL) at the time of the surveys are also indicated.

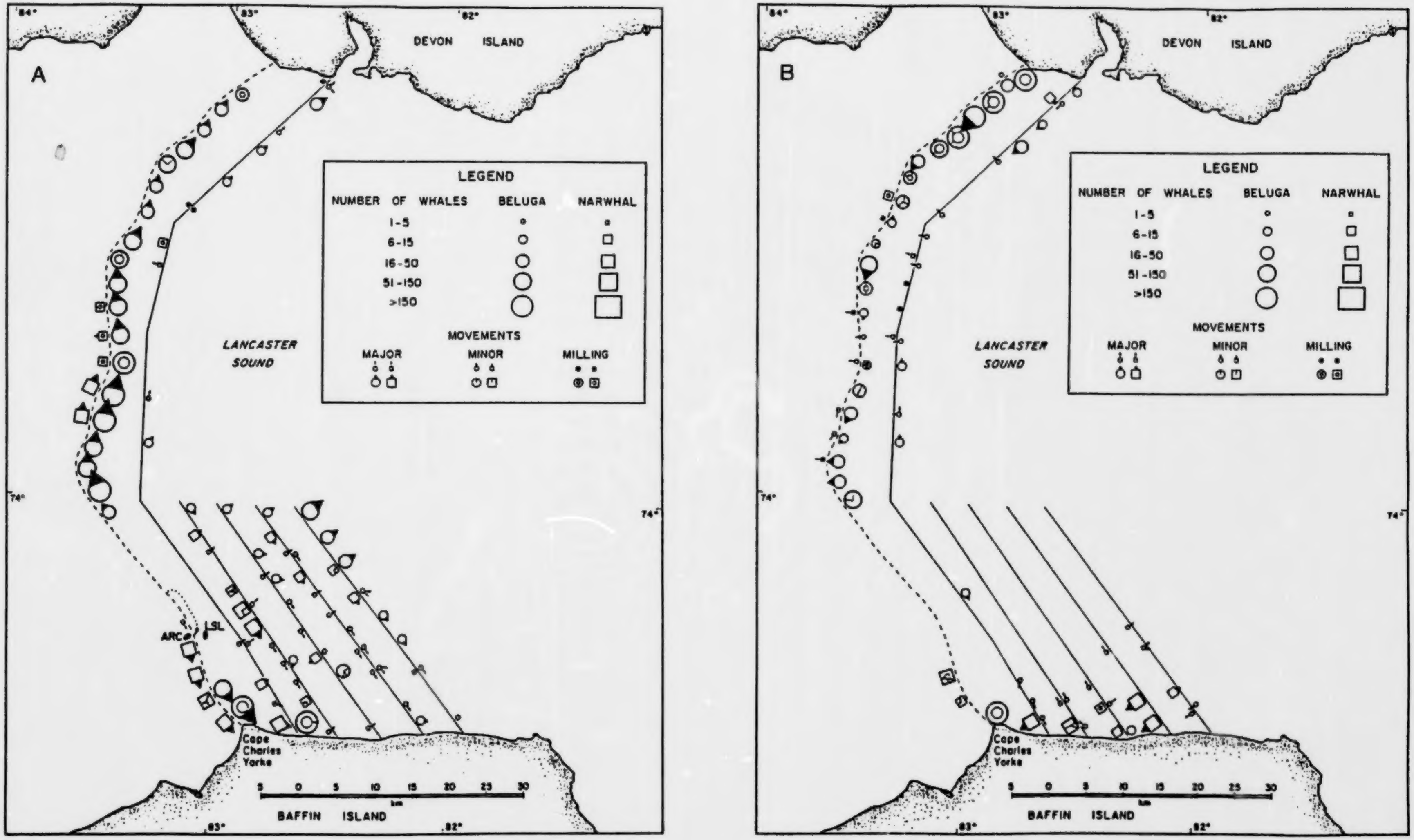
No narwhals were present in the 27-km stretch of ice north of the ships. South of the ships, narwhals were swimming rapidly ahead of the southward moving ships (Fig. 14A).

Documentation of the return to normal conditions was hindered by fog on 30 June and the appearance of cracks in the fast ice on 1 July causing many whales to move into the ice and away from the edge. Nevertheless, it was apparent that even 45 h after the ships started up at the ice edge, beluga distribution along the ice edge and offshore had not returned to normal (Fig. 14B). The ships were 45-50 km into the ice at this time but, based on previous years' data, some relatively low-level ship noise would still have been reaching the ice edge. Beluga distribution was close to normal 16 h later on the morning of 2 July. The distribution of narwhals on 1 July appeared to be fairly normal but so few whales were present that the situation was difficult to evaluate.

Overall, the results in 1984 were similar to those obtained in 1982 and 1983. There was no evidence that the whales were reacting any less strongly in 1984 than in previous years. As in 1983, both species of whales reacted very strongly to the approaching ships and to the start-up and operations of the ships along the ice edge. Narwhals returned to normal distribution patterns much sooner than belugas and appeared to be less disturbed by the ships when they were stopped and when they were icebreaking at distances of over 30 km into the ice.

CONCLUSIONS

The results from the three years of study clearly demonstrate that belugas and narwhals in the High Arctic are highly sensitive to disturbance by shipping in the spring. However, the two species respond in different ways that reflect their overall survival strategies. We have designated these as the 'flee' response of the beluga and the 'freeze' response of the narwhal. The following observable or audible behavioural traits constitute the two patterns: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DEVON ISLAND
LANCASTER SOUND
BAFFIN ISLAND
Cape Charles Yorke
ARC
LSL
LEGEND
NUMBER OF WHALES
BELUGA
NARWHAL
1-5
6-15
16-50
51-150
>150
MOVEMENTS
MAJOR
MINOR
MILLING
5 0 5 10 15 20 25 30
km

Fig. 14. Distribution and directions of movement of narwhals and belugas recorded during aerial surveys on (A) 29 June 1984 (18:30-20:30) and (B) 1 July 1984 (15:20-17:20). The positions of the MV Arctic (ARC) and CCGS Louis St. Laurent (LSL) at the time of the survey are also indicated. The movements of the ships during the survey are indicated by the dotted line.

Belugas	Narwhals
- rapid movement	- slow movement or motionless
- herd cohesion but loss of pod integrity	- pod cohesion, body contact, no herd formation
- diving asynchronous, shallow, 'porpoising'	- sinking submergence
- strongly pagophilic (i.e. ice 'hugging') and coast-seeking, sub-ice movement	- strongly pagophilic, possibly offshore seeking, sub-ice movement
- alarm calls	- silent

The Inuit recognize these behavioural suites under one causative concept 'ardlingayuk' - 'fear of killer whales'. It may be reasonable to view the responses of belugas and narwhals to potentially threatening situations, such as ships, within an 'ardlingayuk' model.

Both belugas and narwhals showed evidence that they were aware of an approaching ship over 80 km away. Beluga 'alarm calls' were given when the MV *Arctic* was 84 km away. Strong avoidance reactions began when the ship was approaching at distances of 35-50 km in two documented cases. Ship approaches caused displacement of both species, but especially belugas. The degree to which belugas are displaced may depend on the proximity to ice cover and shallow coastal waters. In response to ship approaches to offshore ice edges, belugas may move over 80 km along ice edges to coastal areas or they may stop moving within 20 km when coastal waters are that close. Narwhals did not move away from disturbances as rapidly as belugas and they did not move as far away. They were occasionally displaced at least as far as 37 km along an ice edge and some animals also dispersed into offshore areas.

It is possible that the strong reactions evinced by the whales were a function of potential entrapment between an approaching ship and the ice edge. We, of course, have no data on how the whales would react to a ship moving parallel to the ice edge and not approaching the whales. However, both belugas and narwhals in offshore waters reacted very strongly when the

Arctic and Louis St. Laurent started-up and moved along the ice edge 20-25 km from the whales. This incident suggests that the strong reactions were not a function of potential entrapment along an ice edge.

Belugas consistently showed greater reactions to ship disturbances than did narwhals. They moved more rapidly away from disturbances, were displaced farther, and returned to disturbance areas more slowly than did narwhals. Apart from their initial reactions to ship approaches, narwhals showed little or no reaction to ship activities such as start-ups or icebreaking when the ships were operating within the fast ice away from the edge; we could not discern any influence of received levels of ship noise as high as 120 dB//1 µPa in the 20-1000 Hz band on their level of vocal activity or on their surface behaviour. The fact that belugas and narwhals returned to the disturbance area when noise levels were higher than those to which they initially reacted suggests that their initial responses were startle responses, and that their sensitivity to ship noise declined subsequently.

Apart from anecdotal accounts of the responses of narwhals to outboards and Inuit hunting, there have been no studies of the responses of narwhals to full-sized ships. However, there have been some studies and observations of the responses of belugas to boat and ship traffic in other areas (see Davis and Thomson 1984 for a review). Belugas have apparently adapted to regular nearby shipping during the open water season in Cook Inlet, Alaska, the Churchill River estuary in Manitoba, and in the Gulf of St. Lawrence. Belugas in the southeastern Beaufort Sea take evasive action to avoid oncoming ships but they react much closer to the ships (2-3 km) than did the whales in Lancaster Sound (M.A. Fraker cited in Davis and Thomson 1984). In each of the above cases, the belugas have been exposed to much higher levels of shipping activity for a number of years. It is possible that the belugas of the High Arctic are 'naive' with respect to shipping and have not had time to adapt or habituate to shipping.

L. Lowry (cited in Davis and Thomson 1984) has noted up to 500 belugas feeding heavily in Kvichak Bay, in inner Bristol Bay, Alaska, during the king salmon run. At this time the bay also supports a very intensive salmon fishery with about 500 fishing boats supported by high-powered tender boats and single-engine float planes. The whales consistently move back and forth through the fishing fleet. This behaviour is markedly different than that observed in Lancaster Sound and is presumably related to the intensive feeding in Kvichak Bay. Belugas along the ice edge in Lancaster Sound are primarily waiting for the ice to break-up so that they can proceed to traditional summering areas in the central Arctic. Since they apparently feed little along these ice edges, the belugas have no strong 'vested interest' in remaining in a particular area when a ship approaches. Later in the summer, in their traditional estuarine habitat, belugas do have a 'vested interest' in remaining in limited and specific habitat as evident by their persistence in using certain estuaries in spite of severe harassment by hunters (Finley et al. 1982; Finley 1982).

Whatever the reasons, the responses of belugas and narwhals to ships in the High Arctic in spring are unprecedented in the marine mammal literature (Richardson et al. 1983).

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Section 2

Report of 1982 Study

A STUDY OF AMBIENT NOISE, SHIP NOISE, AND THE REACTIONS OF NARWHALS AND BELUGAS TO THE MV ARCTIC BREAKING ICE IN ADMIRALTY INLET, N.W.T. - 1982

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Canada Dept. of Indian Affairs and Northern Development
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February 1983

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INTRODUCTION

In recent years, there has been an increasing concern about the potential effects that year-round icebreaking in arctic waters might have on marine mammals. There have been several projects proposed to ship resources from the Canadian arctic to southern markets. These projects would introduce a combination of icebreaking and underwater noise into the arctic marine environment. In addition to the general concern about winter shipping, the Inuit hunters of Arctic Bay believe that increasing ship traffic into the Nanisivik mine and increasing hunting pressure are causing narwhals to abandon their traditional summering grounds in Admiralty Inlet, northern Baffin Island. The hunters believe that displacement is resulting in increased mortality of narwhals from ice entrapment in unfamiliar areas. In response, the Hunters and Trappers Association of Arctic Bay decided to close the ice edge hunt in 1982 and to restrict the harvest during the ice crack hunt to 30 narwhals. The hunters were concerned, therefore, when Canarctic Shipping announced that the ore carrier MV Arctic would be breaking into the fast ice of Admiralty Inlet in late June, much earlier than usual, in an exploratory attempt to increase the length of the commercial shipping season into the Nanisivik mine.

This study was quickly organized (five days from contract award to start of field work) in response to the above concerns. It was designed to provide information on the behavioural responses of narwhals to the MV Arctic as it approached the Admiralty Inlet ice edge and as it conducted icebreaking operations in the fast ice. The study was also designed to document ambient levels of underwater noise and the noise associated with the ship operating in open water and in the ice. These acoustic measurements also provided information on the vocal behaviour of narwhals and belugas and changes in this behaviour in the presence of ship noise. This report presents the results of these studies.

The report is not intended to be a major review of the effects of ship noise on marine mammals. Rather, it presents a factual account of the observations made during the study and some tentative interpretations of the results. The study presents an initial attempt to quantify the responses of arctic marine mammals to ships. Much larger sample sizes in a variety of situations will be necessary before any definitive conclusions about the effects of arctic shipping can be drawn.

Subsequent to the 1982 prototype study reported here, additional studies were conducted in 1983 and 1984 under the auspices of DIAND and various co-sponsors. A larger, more comprehensive study was conducted at the Lancaster Sound ice edge in the spring of 1983. This study had a much more reasonable time for project planning and involved several interrelated biological and acoustical components. The results of the 1983 study are reported in

Finley, K.J., G.W. Miller, R.A. Davis and C.R. Greene. 1984. Responses of narwhals (Monodon monoceros) and belugas (Delphinapterus leucas) to ice-breaking ships in Lancaster Sound - 1983.Rep. by LGL Ltd., King City, Ontario, for Canada Department of Indian Affairs and Northern Development, Ottawa. 117 p.

The 1984 study consisted of a series of aerial surveys of whale distribution and movements along the Lancaster Sound ice edge during the period when the MV Arctic and CCGS Louis St. Laurent arrived at the ice edge. The results of this study are reported by

Miller, G.W and R.A. Davis. 1984. Distribution and movements of narwhals and beluga whales in response to ship traffic at the Lancaster Sound ice edge - 1984. Rep. by LGL Limited, King City, Ontario, for Canada Department of Indian Affairs and Northern Development, Ottawa. 34 p.

The results and major conclusions of the three year study are combined and integrated in an overview report

Finley, K.J. and R.A. Davis. 1984. Reactions of beluga whales and narwhals to ship traffic and ice-breaking along ice edges in the eastern Canadian High Arctic: 1982-1984. An overview. Rep. by LGL Limited, King City, Ontario, for Canada Department of Indian Affairs and Northern Development, Ottawa. 42 p.

METHODS

Design of Study

The study in 1982 had two related operational field components: behavioural observations and acoustic measurements. The behavioural component consisted of visual observations of whale behaviour and distribution in relation to the presence of the ship. These observations were made by ice-based crews using snowmobiles for support and aerial observations from a helicopter (Bell 206-B). The acoustic measurements were made using hydrophones deployed at a series of camps near the ice edge across Admiralty Inlet. The acoustic program provided information on natural ambient noise levels, mammal vocalization types and frequencies, and radiated noise levels from the ship at various distances and operational conditions.

The study was designed to have three temporal components. A pre-disturbance control period was used to document undisturbed behaviour and distribution of whales, and natural ambient noise levels. The pre-disturbance control period was planned to be from 3 to 5 days duration. Unfortunately, this objective was not achieved since the ship arrived on 28 June rather than on 1 July as originally planned. In addition, the crew with the principal task of making behavioural observations was stranded on an ice floe on 25 and 26 June.

The second part of the study was the 'disturbance phase'. This phase was defined as beginning when underwater sound from the MV Arctic was first detectable by our hydrophones. The final, post-disturbance control phase of the study was arbitrarily defined as beginning when whales returned to the ice edge after the ship had penetrated south toward Strathcona Sound.

Field and Ship Schedule

On 26 June a field camp (camp #1) was established in mid sound about 2.5 km from a stable ice edge that extended 36 km across Admiralty Inlet from Elwin Inlet to Cape Crauford (Fig. 1). Underwater recordings of ambient noise were made from this location and observations were conducted from the

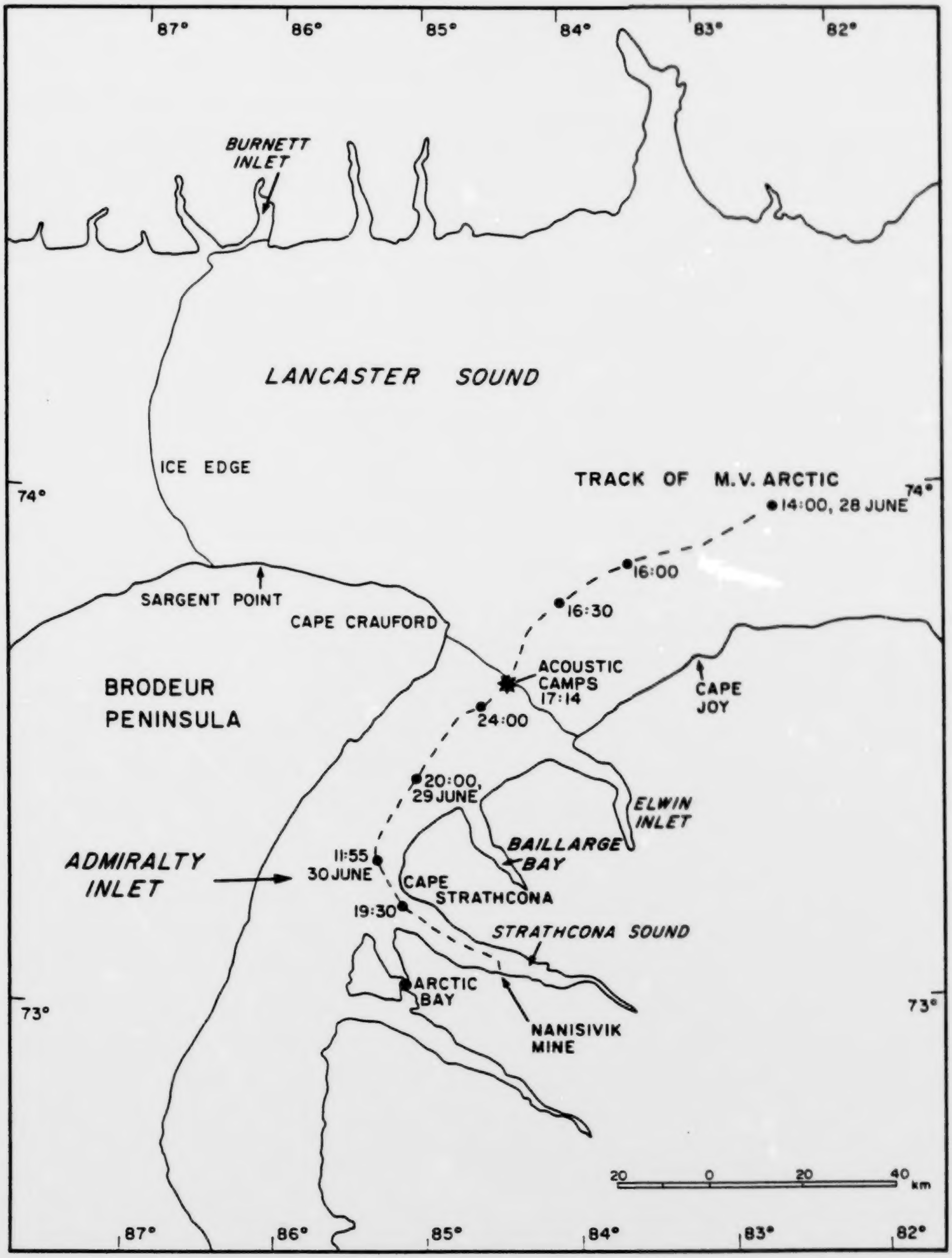
87°
86°
85°
84°
83°
82°
BURNETT INLET
LANCASTER SOUND
ICE EDGE
TRACK OF M.V. ARCTIC
74°
74°
14:00, 28 JUNE
16:00
16:30
SARGENT POINT
CAPE CRAUFORD
BRODEUR PENINSULA
ACOUSTIC CAMPS 17:14
24:00
CAPE JOY
20:00, 29 JUNE
ELWIN INLET
BAILLARGE BAY
ADMIRALTY INLET
11:55 30 JUNE
CAPE STRATHCONA
19:30
STRATHCONA SOUND
ARCTIC BAY
NANISIVIK MINE
73°
73°
20
0
20
40
km
87°
86°
85°
84°
83°
82°

Fig. 1. The study area showing the position of ice edges in Lancaster Sound-Admiralty Inlet and the track of the icebreaker MV *Arctic* between 28 and 30 June, 1982.

ice edge until late on 27 June. The camp was then relocated about 4 km farther west, after consultation with Canarctic Shipping Ltd., to be nearer to the projected path of the MV Arctic. Observations and underwater recordings were conducted from this location (camp #2) until 30 June. The carrier MV Arctic arrived at the Admiralty Inlet ice edge at 17:14 EST on 28 June and made its way down the centre of the inlet arriving at Nanisivik mine about midnight on 30 June. The carrier averaged 1.2 km/h (0.75 miles/h) over the 60 km of fast ice to the mouth of Strathcona Sound. The ship track is shown in Figure 1.

Whale Behaviour and Distribution

Ice-based Observations

Numbers of marine mammals, their direction of movement and general behaviour (i.e. resting, travelling, social interaction and feeding) were recorded during the study period. An attempt was made to record duration of surface and dive sequences of individual animals, but without a high vantage point this was usually unsuccessful, especially when several groups of whales were in the area.

At 12:00 on 28 June, two observation camps were manned by two observers in each camp. The camps were located along the ice edge approximately 5 km on each side of the projected path of the ship. These camps were manned until 20:00 on 28 June and again on 29 and 30 June. Observations after 1 July were hampered by poor weather and unstable ice conditions.

Aerial Observations

Helicopter support was available only on an opportunistic basis; thus, it was not possible to schedule flights for ideal survey conditions and times. Nonetheless, useful surveys of the Admiralty Inlet ice edge were conducted on 27 June (start at 21:37), 29 June (20:51) and 30 June (20:30). The last two surveys also included part of the Lancaster Sound ice edge. The surveys were flown at an altitude of 300-500 m along ice edges and coastal areas and the observer, situated on the side closest to the ice edge, recorded observations of numbers, group size, direction of movement and general behaviour of all marine mammals. When possible, the observer also included information on the relative age and sex composition of groups of narwhals.

An additional survey was conducted on 4 July. This survey followed the track of the MV Arctic between the ice edge and Strathcona Sound. This track had been used by the ship during both its inbound and outbound (2 July) voyages. Part of the Admiralty Inlet ice edge was also included on this survey.

Acoustic Measurements

Locations

Recordings were made from two base camps. Camp #1 was located on the ice, 2.5 km from the ice edge. Recordings were made at this camp between 02:48 and 22:00 on 27 June. Camp #2, 500 m from the ice edge, was occupied late on 27 June and the first recording was made at 00:34 on 28 June (Fig. 1). This camp was occupied until 30 June. Additional recordings were made on 30 June at the ice edge and in the ship track, about 18.5 km from the ice edge.

The water depth at camps 1 and 2 was about 340 m and the ice thickness at camp 2 was 1.5 m on 27 June.

Equipment

The basic components of equipment used in the field included hydrophones, amplifiers, and tape recorders. We used a wideband model H56 hydrophone (useful response from 10 Hz to 65 kHz, low noise) and two bender hydrophones, especially sensitive at low frequencies (below 1000 Hz) with very low self noise. We used the H56 and one bender at a depth of 20 m and the second bender at 2.5 m for comparison of sound levels at deep and shallow depths.

Each hydrophone unit included a built-in low noise pre-amplifier. On the ice, we used separate post-amplifiers with adjustable gain (in 10 dB steps) to condition the signal for optimum level for the tape recorder. All equipment was battery powered, assuring a quiet camp without 60 Hz electrical fields to contaminate the data. An accident with the wideband post-amplifier forced us to use the microphone input to the tape recorder for the H56 hydrophone, but this was satisfactory and did not degrade the quality of the data.

A Sony model TC-D5M cassette tape recorder was used. It had two channels and a servo-controlled capstan to assure constant speed; its calibrated response extended from 10 to 17,000 Hz.

Recordings

Recordings (10-min duration) of ambient noise were made at hourly intervals on 27 and 28 June. As the ship approached on 28 June, continuous recording was begun at 16:53. The ship was about 6.4 km away at this time. The continuous recording was terminated at 23:04 when the ship was about 7.4 km into the ice. Recordings on an hourly basis were resumed at 07:00 on 29 June, although continuous recordings of the backing and ramming phases of the ice-breaking cycle were made as appropriate.

Recording was normally done with the two hydrophones at 20 m depth. Occasionally, bender hydrophones were used to compare the sound levels at shallow (2.5 m) and deeper (20 m) depths.

Analysis Techniques

A minicomputer (Data General Nova 3) facility with a 12-bit analog-to-digital converter for transforming input data and a digital plotter for preparing graphs of output data was used. Programs are tailored for each application and include the specific calibration terms (vs. frequency and record level settings, for example) appropriate for a given field experiment.

A/D Conversions

After studying the logs and listening to the sounds of a given activity, we selected a representative segment for analysis. Each segment was digitized at three different sample rates to provide three different spectral resolutions (see next section). We low-pass filtered the signals before sampling to assure no contamination from aliasing. We scanned the resulting samples to be certain there was no saturation of the A/D converter, computed and subtracted the average value, and stored the samples.

Spectrum Analysis and Plotting

For spectrum analysis we used a weighted, overlapped segment averaging technique. Fast Fourier Transforms were computed for overlapped sections of the stored samples, the powers in each frequency element were computed, then successive powers (for the corresponding elements) were averaged. Table 1 provides some of the attributes of the resulting power spectra and their plots.

Table 1. Attributes of spectrum analyses for different sampling rates.

Sample Rate, Hz	Data Length s	Effective Spectral Resolution, Hz	Plotted Frequency Range, Hz
2048	8.5	1.7	10-1000
8192	2.0625	13.7	80-4000
32,768	0.515625	54.7	320-16,000

Readers should be cautious in reading spectrum levels for tonal components from the power spectral plots. Theoretically, tones have an infinite spectral density; one must compute the power at the tonal frequency, which may be presented in dB with respect to 1 microPascal, for example. Conversion from the plotted spectral density involves multiplication by a bandwidth correction term, which is the effective bandwidth of each analysis cell.

Band Level Analysis

Summing over pre-defined ranges of frequency cells in the averaged spectra provided band levels of noise. We selected frequency bands with limits corresponding to frequencies for which the spectrum contained values, then used half of the powers in the first and last cells plus the powers in all the cells in between. Thus, we did not attempt to estimate the band level for the 10 to 100 Hz band when the cell spacing did not provide power computations for cells centred at 10 and 100 Hz, for example. The results of the band level analyses are presented in Appendix A.

Data Presentation

The results are in the form of graphs and tables. Each figure is comprised of four plots of spectral densities, each for a different range of frequencies. The top left plot spans the frequency range from 10 to 500 Hz and the top right plot continues for 500 to 1000 Hz; these two plots come from a single spectrum analysis of the 8.5 s data sampled at 2048 samples/s. The lower left plot extends to 4000 Hz and is derived from the analysis of the 2.0625 s data sampled at 8192 samples/s. The lower right plot extends to 16,000 Hz and is derived from the analysis of the 0.515625 s data sampled at 32,768 samples/s. Differences in the data in the different plots at common frequency regions (like the region to 4000 Hz in the plot to 16,000 Hz) may be the result of two causes: one, the length of time varies from about 0.5 to 8.5 s, and the received signals may change somewhat over that length of time, or two, the analysis resolution varies from 1.7 to 54.7 Hz. Tones are especially likely to appear differently for different resolutions, although correction for the bandwidth differences should result in close to the same levels for steady tones.

Two figures display spectra in pairs from 10 to 500 Hz and from 500 to 1000 Hz; one pair is computed for the low-frequency hydrophone at 2.5 m and the other for the low-frequency hydrophone at 20 m.

Whale Vocalizations

Underwater recordings (10 min duration) of animal vocalizations were made at approximately 2-h intervals during the day between 12:00 on 27 June and 14:00 on 30 June (Table 2).

Table 2. Schedule of underwater recordings at the Admiralty Inlet ice edge, 27-30 June, 1982.

	June			
Time (EST)	27*	28**	29**	30**
08:00		+		+
10:00		+	+	+
12:00	+	+	+	+
14:00	+	+	+	+
16:00	+	+	+	+***
18:00	+	+	+	
20:00	+	+		
22:00		+	+	

* Recorded at 2.5 km from the ice edge.

** Recorded at 0.5 km from the ice edge.

*** An additional recording was taken at 17:00 from the ice edge in the presence of narwhals.

From these 10-min recordings we randomly selected 1-min segments for spectrographic analysis. When ship noise predominated, we attempted to select the 30-s segment with the least amount of ship noise.

Spectrograms were produced on a Spectral Dynamics (SD 301C) real-time analyzer, which had an effective analyzing bandwidth of 60 Hz. Preliminary power spectral density analysis indicated that most of the sound energy from marine mammal vocalizations was below 4 kHz. The tape was analyzed for two bandwidths (0-8 kHz and 6-14 kHz) in order to expand the display and at two speeds (2 and 4 cm/s) for comparative resolution. An additional spectrogram, run at 4 cm/s, covered the 0-12 kHz bandwidth. Corresponding segments on the five spectrograms were examined simultaneously while listening to recordings played at normal and at 1/2 speed on a reel-to-reel recorder. From the spectrograms run at 4 cm/s we measured the initial, final, lowest and highest frequencies (± 100 Hz) and durations (± 0.15 s) of animal sounds. The types of vocalizations were determined from visual inspection of the spectrograms and aural impression of the sound. All distinctive odontocete vocalizations were catalogued and categorized (Appendix B) and the number of vocalizations of each type was counted for each 1-min segment of the spectrogram. Vocalizations of bearded seals (Erignathus barbatus), ringed seals (Phoca hispida), walruses (Odobenus rosmarus) and miscellaneous unidentified sounds were also noted and, where possible, quantified.

RESULTS

Ice Conditions

The position of the fast ice edge across Parry Channel (Lancaster Sound-Barrow Strait) in spring is variable from year to year. This edge can be the critical determinant of the timing of spring migration into the high arctic by narwhals and belugas (Koski and Davis 1979; Koski 1980). In most years the ice edge occurs across Barrow Strait in June and July. Thus, whale migration into and through Lancaster Sound is unimpeded by fast ice. In these conditions, belugas migrate along the north side of Lancaster Sound and do not enter Admiralty Inlet (Davis and Finley 1979).

In 1982, fast ice extended across Lancaster Sound from the Brodeur Peninsula (just west of Admiralty Inlet) to Devon Island (Fig. 1). This edge persisted at least until early July. As a result, belugas migrating into Lancaster Sound were unable to move into their summering grounds in the central high arctic. They responded by following the ice edge south across Lancaster Sound and into the Admiralty Inlet area. This allowed us to compare the responses of both belugas and narwhals to the passage of the ship. On the other hand, it made interpretation of whale vocal behaviour extremely difficult. Virtually all of our recordings that contain whale calls were taken when both belugas and narwhals were present.

Ice conditions in Admiralty Inlet were fairly typical in 1982. Break-up of the fast ice in the northern part of Admiralty Inlet usually proceeds from north to south with de-segmentation of large sheets along recurring fracture lines across the inlet; these fracture lines emanate from predictable points along shore. Four major cracks were encountered during our travel by snowmobile between Strathcona Sound and Elwin Inlet. [According to Inuit hunters these cracks recur in these locations every year.] The largest of these cracks, located at the mouth of Baillarge Bay, presented a considerable obstacle to travel on 27 June and required a precarious portage of equipment along an ice shelf beneath 600-700 m cliffs. The passage of the MV Arctic through Admiralty Inlet caused some de-stabilization on the seaward side of the northernmost ice crack. The de-stabilization led to a slight shifting of the positions of the two halves of the outermost ice segment.

The ship track through the fast ice was crossed three times by snowmobile on 5 and 6 July. The track was crossed without undue difficulty, although on one occasion a hunter nearly lost his snowmobile when he misjudged the stability of some ice rubble in the track. The ice rubble in the track had not refrozen after the outbound passage of the ship. The ship left Nanisivik at midnight on 2 July and followed the original track during its outbound voyage on 3 July.

Description of Whale Vocalizations

When the noise of the MV *Arctic* was not predominant, recorded samples were nearly saturated with marine mammal sounds. The variable frequency signals of <2 s duration, typical of narwhals and belugas, were the predominant sounds, usually overlying the distinctive low-frequency, long-duration, trills of bearded seals. Occasional calls from bowhead whales (*Balaena mysticetus*), walruses, ringed seals, and unidentified 'non-odontocetes' were also heard. Overlapping signals could usually be distinguished on the basis of relative sound level with the aid of the spectrographic display.

In addition to 'click series', at least 77 distinctive odontocete whale signals were identified on 13 1-min segments of spectrographic display. These signals covered the general range of sound emissions characteristic of most odontocetes--narwhals and belugas in particular (see Ford and Fisher 1978; Fish and Mowbray 1962; for example)--but the sounds could not be readily assigned to one species or the other because they have been described only in general terms and no published descriptive lexicon of sounds exists for the two species. The 77 calls illustrated and described in Appendix B are catalogued by structural and aural qualities into five major groups: (1) tonal sounds (whistles), (2) sweep-frequency sounds (yelps, chirps, etc.), (3) complex sounds (screams, wails, blares, etc.), (4) pulsive sounds (ratchets, crickets, croaks, etc.), and (5) miscellaneous sounds. 'Click series', usually associated with echolocation, were treated as a distinctive category of sound emissions. In general, the sounds fell clearly into the above categories but this was not always the case and 'hybrid' calls were recognized.

The tonal calls (whistles) were narrow-band sounds with no detectable harmonics and varied greatly in structure from 'morse-like' signals of constant frequency to long undulating whistles and stepped-frequency whistles. The latter category often contained distinctive sounds of a two- or three-part structure that were heard only on single occasions. Often the constant-frequency whistles were repeated almost identically in series of irregular intervals. Most of the tonal calls lasted 0.5-1.5 s in the frequency range of 1 to 9 kHz.

The sweep-frequency calls (chirps, yelps, etc.) were generally low-frequency (<3 kHz) sounds, individually of short duration (<0.5 s), but often repeated at regular intervals to form discrete series (see Appendix B).

Complex calls were relatively long in duration (1-2 s) and often had harmonic structure. These sounds were grouped from aural impression and by spectrographic appearance. At low frequencies the complex calls had unusual tonal qualities described as 'wails' or blares'. Those calls with wideband harmonics sounded like strident 'screams' or 'screeches' (c.1 to c.12 in Appendix B); on spectrographs these sounds may appear as 'burst-pulse' structures (Watkins 1967).

The pulsive sounds generally had 'raspy' qualities that were variously described as 'croaks' and 'ratchets' at low frequencies (<3 kHz) or 'insect-like buzzes' at high frequencies (to 10 kHz). Four of these distinctive call types (Appendix B, p. 7 to p. 10) contained a brief introductory component followed by a longer, broadband component of different frequency emphasis. These calls were often repeated at regular intervals of 3-5 s.

The miscellaneous calls covered a wide range of sounds that could not be readily categorized.

'Click series' were mostly narrow-band signals like those attributed to the narwhal by Watkins et al. (1971) and Ford and Fisher (1978). The click series, which often lasted several seconds, had a relatively constant repetition rate (5-13/s, mean 8.4 ± 2.7, n = 41) as well as constant frequency (within the range from 1.5 to 8.0 kHz) throughout a series. Up to 30 or 40 click series could sometimes be distinguished in a 1-min segment of spectograph display. Both narwhals and belugas are known to emit high-frequency click series that were beyond our equipments' recording capabilities, but since the high frequency clicks are so strongly directed and rapidly attenuated it is unlikely these sounds would have reached our recording position.

Pre-Disturbance Period

Ambient Noise

Measurements of natural ambient noise were made at camp #1 from 12:00 to 22:00 on 27 June. The hydrophones at this camp were 2.5 km from the ice edge. Ambient noise was dominated by animal sounds, primarily bearded seals, belugas and narwhals. Figure 2 presents the ambient spectra for a sample of typical noise levels taken at 13:14 on 27 June. The spikey appearance of the spectra is caused by the animal calls. In general, received levels ranged between 50 and 65 dB//(1 μPa)^2/Hz at frequencies up to 4 kHz. Levels decreased at higher frequencies reaching about 25 dB//(1 μPa)^2/Hz at 16 kHz (Fig. 2). The results from the analyses of various bandlevels are presented in Table A-1.

Ambient noise at camp #2 (500 m from ice edge) was measured at 00:36 (Fig. 3) and from 06:20 to 11:00 on 28 June. Ambient levels at 00:36 were similar to those earlier in the day, although there were fewer spikey peaks since fewer animals were calling. The spike at 2 kHz (probably a bearded seal) is an exception (Fig. 3).

Ambient noise levels on the morning of 28 June (Figs. 4 and 5) were similar to those on 27 June. Again, animal calls dominated the noise. Levels were slightly higher (about 5 dB) at 06:20 (Fig. 4) than at 09:15 (Fig. 5). The difference was about 10 dB at 16 kHz. Ambient levels at 10:20

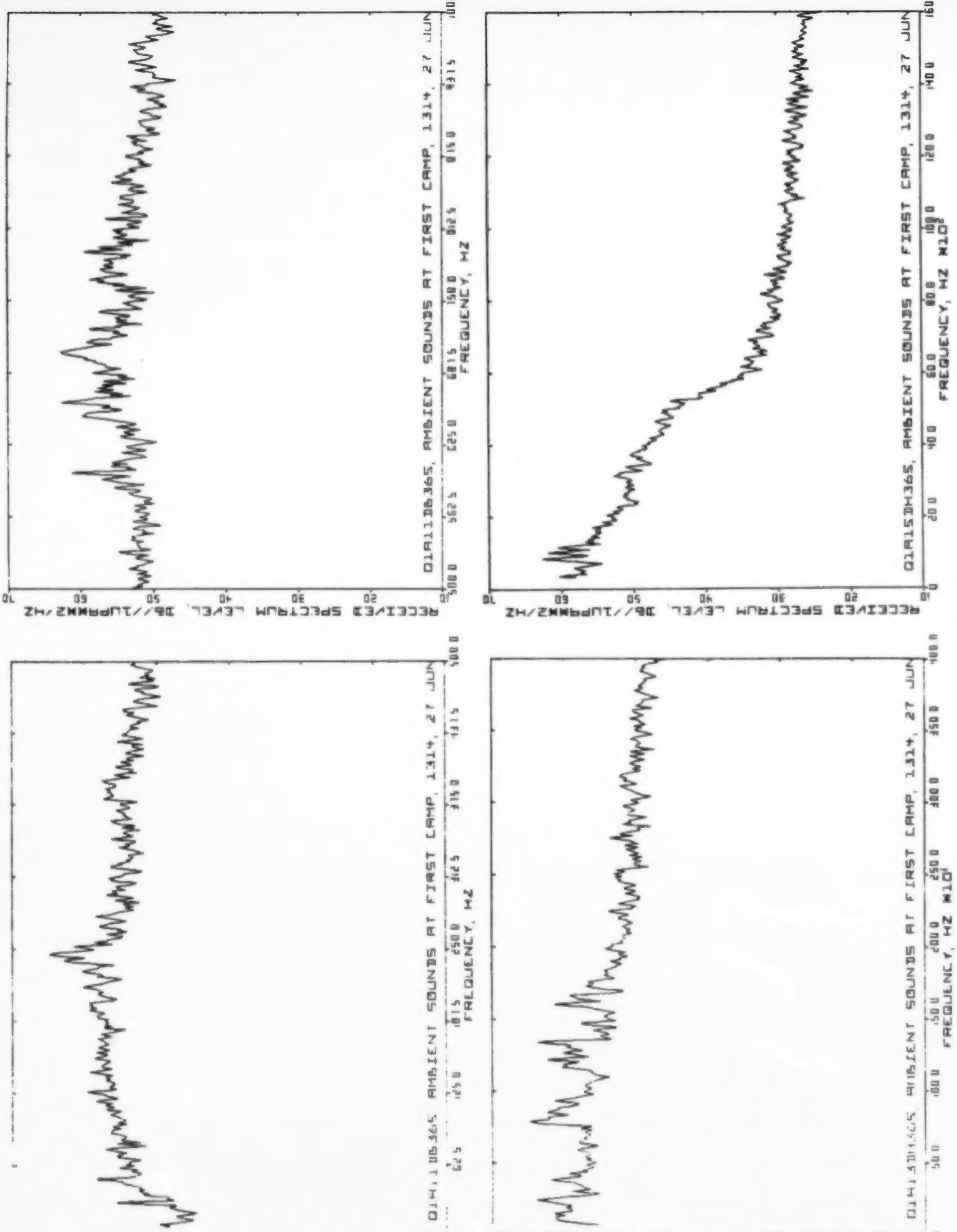

Fig. 2. Ambient noise spectra at 13:14, 27 June.

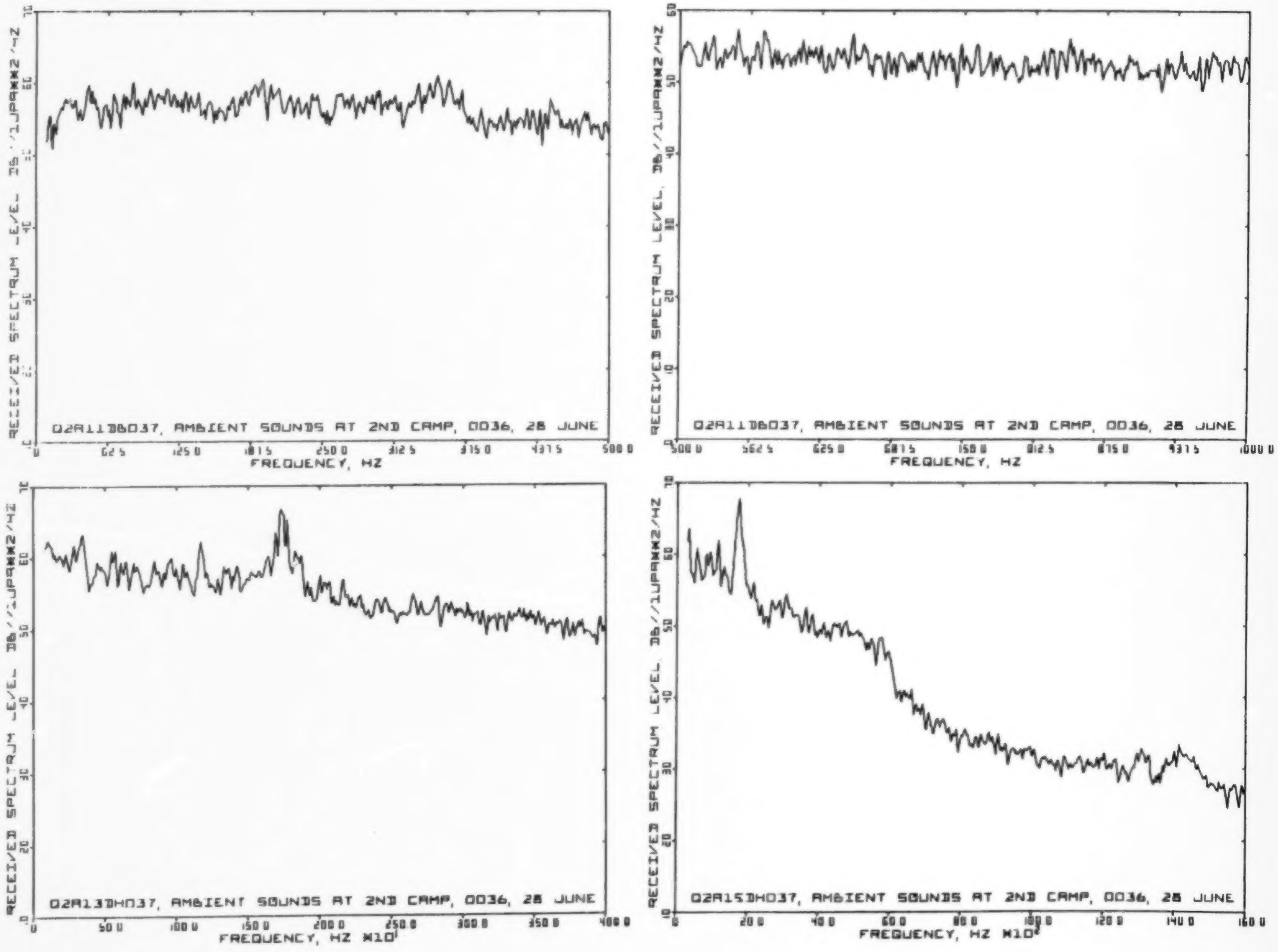

Fig. 3. Ambient noise spectra at 00:36, 28 June.

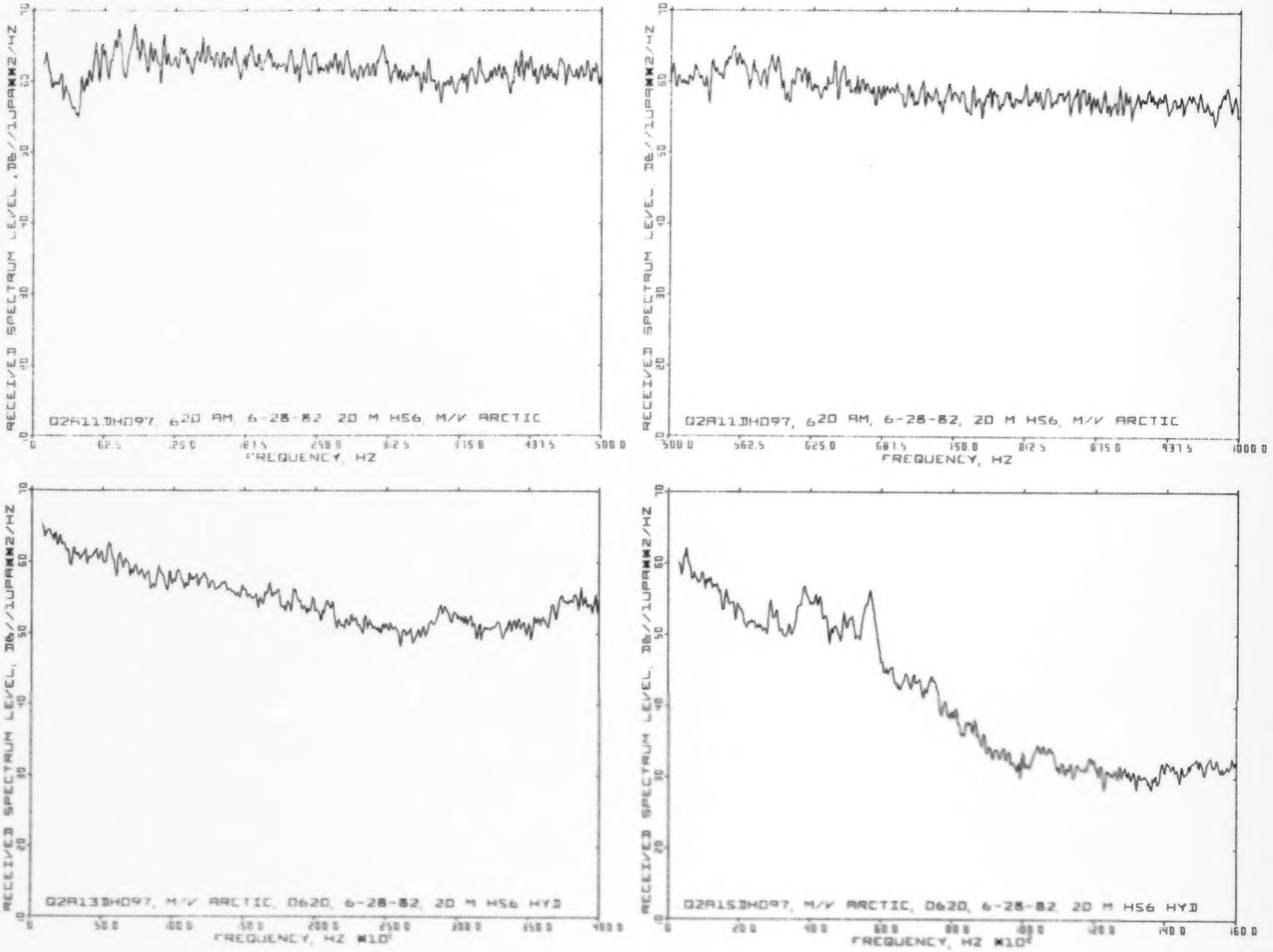

Fig. 4. Ambient noise spectra at 06:20, 28 June.

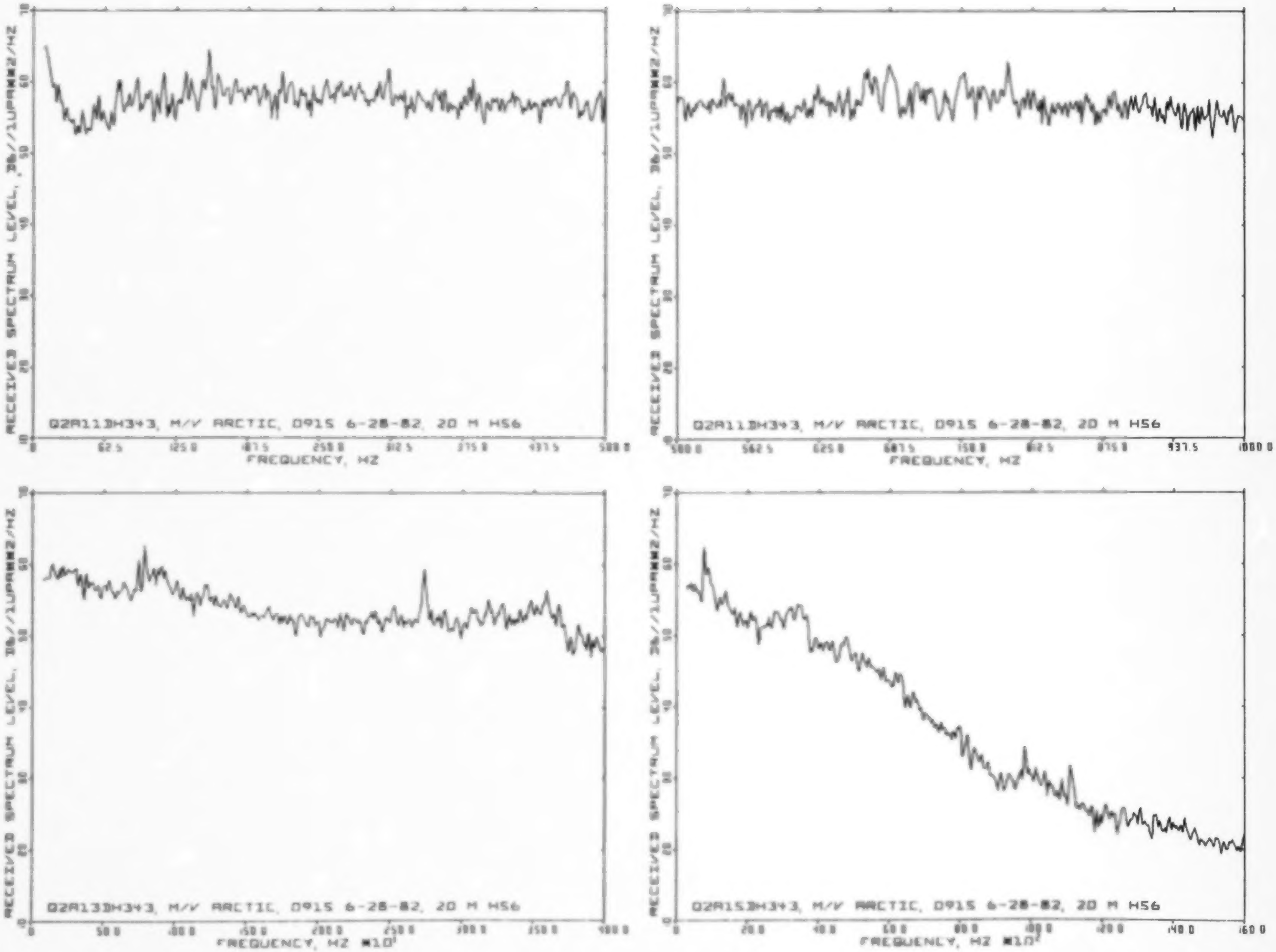

Fig. 5. Ambient noise spectra at 09:15, 28 June.

(Fig. 6) were similar to those at 06:20. These differences are due to natural variation in noise levels.

All of the above measurements of ambient noise were made under relatively calm conditions. Similarly, all measurements made later on 28 and on 29 and 30 June were made under relatively calm conditions. The audible characteristics of ambient noise were different on 28 June (than on 27 June), when the hydrophones were closer to the ice edge and much meltwater drainage of surface water through seal holes was occurring.

The ambient noise spectra discussed above were selected to exclude the calls from nearby bearded seals. Figure 7 presents the spectra when nearby bearded seals were calling.

Whale Behaviour and Distribution

Narwhals were present along the Admiralty ice edge on 24 June but we were unable to obtain information on numbers and behaviour because of unstable ice. Both narwhals and belugas followed the retreat of the ice edge into Admiralty Inlet on 25 June; from our precarious position on a departing ice floe we saw about 200 belugas and 40 narwhals moving south through leads on the east side of Admiralty Inlet, then west along the newly formed ice edge.

No whales were present along the ice edge north of camp #1 during observations from 11:30 to 16:00 on 27 June. However, the observer could detect surface activity of whales toward the eastern side of the inlet.

The Admiralty Inlet ice edge and part of the adjacent eastern coast was surveyed by helicopter beginning at 21:37 on 27 June. Whales were found only along the eastern quarter of the ice edge (Fig. 8). A total of 42 narwhals and 18 belugas were recorded; all were within 1.5 km of the ice edge and most were within 0.5 km. Additional whales were present several km farther offshore but they could not be enumerated.

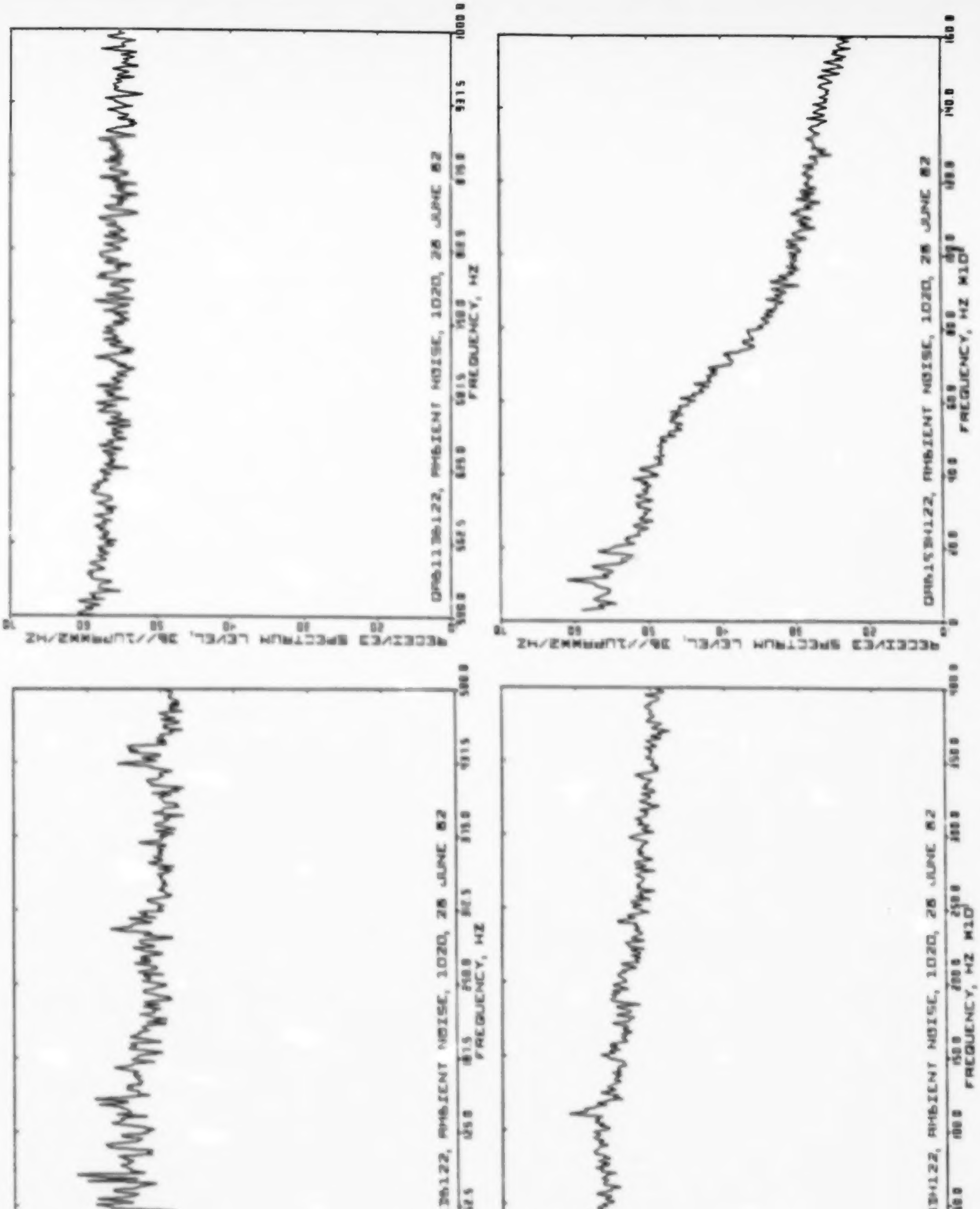

Fig. 6. Ambient noise spectra at 10:20, 28 June.

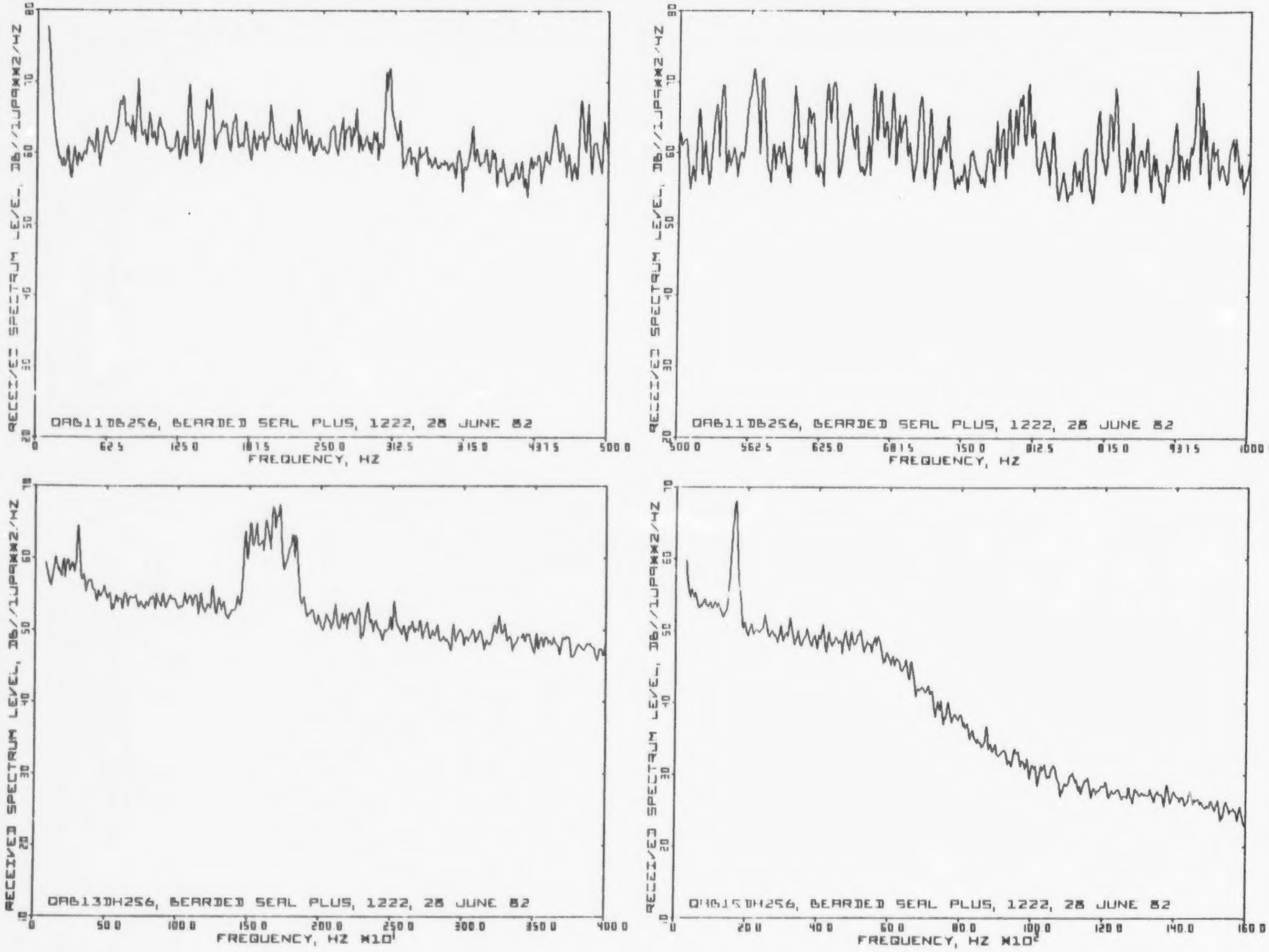

Fig. 7. Ambient noise spectra at 12:22, 28 June.

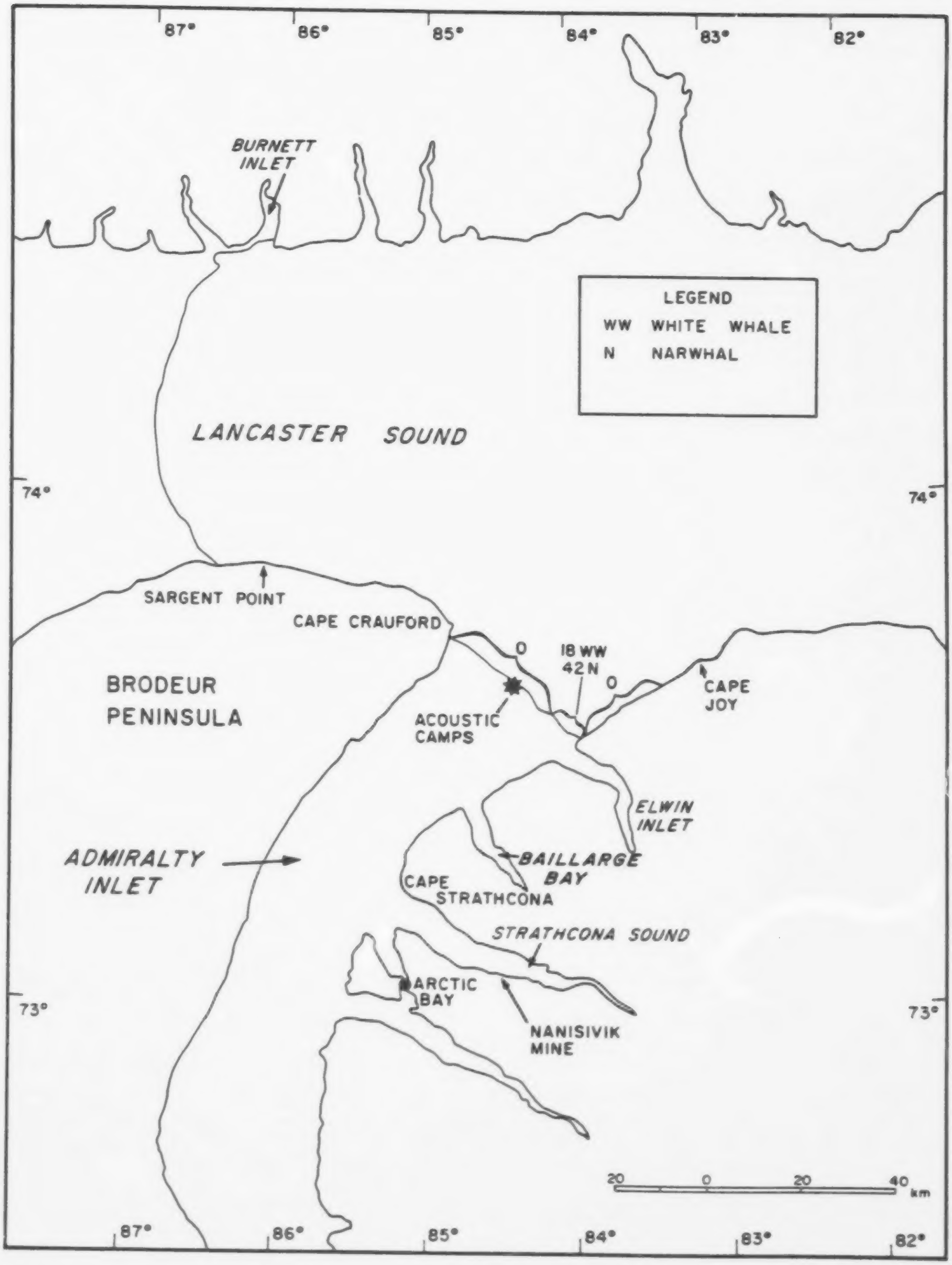
87°
86°
85°
84°
83°
82°
BURNETT INLET
LEGEND
WW WHITE WHALE
N NARWHAL
LANCASTER SOUND
74°
74°
SARGENT POINT
CAPE CRAUFORD
0
18 WW
42 N
0
CAPE JOY
BRODEUR PENINSULA
ACOUSTIC CAMPS
ELWIN INLET
ADMIRALTY INLET
BAILLARGE BAY
CAPE STRATHCONA
STRATHCONA SOUND
ARCTIC BAY
NANISIVIK MINE
73°
73°
20
0
20
40
km

Fig. 8. Distribution and numbers of narwhals and white whales (belugas) along the Admiralty Inlet ice edge between 21:37 and 22:02, 27 June.

The whales recorded on the survey were present in small, dispersed groups (Table 3). Movement was casual and generally parallel to the ice edge. Slightly more groups were moving east than were moving west.

On 28 June, only a few whales were recorded along the ice edge at camp #2 from 07:00 to 12:00. A dispersed group of nine belugas moved slowly eastward past the observer between 07:54 and 08:03. The group, consisting of four adults and five subadults, was within 150 m of the ice edge. A dive sequence of one of the adults consisted of shallow dives of 15, 8, 8, 8, 10 and 9 s with surfacings of less than 1 s. Some of the members of this group stopped about 1 km from our vantage point and began diving under the ice, apparently feeding. This behaviour lasted until 08:45 when the animals disappeared from view.

At 11:30, an adult and subadult (probably a 2 year-old) beluga moved west past our vantage point at a distance of about 400 m from the ice edge. It was apparent that the adult was feeding while the subadult followed and remained at the surface for longer periods (Fig. 9).

Based on several year's experience with belugas, the senior author concludes that the behaviour of both of the above groups was normal and typical of undisturbed belugas.

Whale Vocalizations

Recordings taken in five samples from 12:00 to 20:00 on 27 June were nearly saturated (25-83 calls/min) with whale calls (Table 4). These calls were comprised largely of tonal sounds (36%-65%, average 53%) and sweep-frequency sounds (10-37%, average 23%). Complex calls, pulsive calls and miscellaneous sounds were heard infrequently.

The number of 'click series' varied widely with none recorded at 18:00 and over 30 series present in the recording at 16:00. Repetition rates varied from 3.2-13.0/s and averaged 6.9 ± 1.6/s (n = 17).

Table 3. Movement and group sizes of belugas and narwhals observed during helicopter surveys of the Admiralty Inlet and Lancaster Sound ice edges, 27, 29 and 30 June, 1982.

Date of survey	Location of ice edge surveyed	Species	Movement of groups re: ice edge (%)					# groups tallied	size ± s.d.
			Parallel (W or N)	Parallel (S or E)	Toward	Away	Resting		
27 June	Admiralty Inlet	Belugas	60	40	0	0	0	7	2.7 ± 2.2
		Narwhals	37	21	0	10	32	19	1.9 ± 1.1
29 June	Lancaster Sound	Belugas	27	28	8	0	37	78	2.8 ± 3.0
		Narwhals	30	3	21	0	47	34	2.9 ± 1.8
30 June	Admiralty Inlet	Belugas	75	0	0	0	25	16	2.7 ± 3.2
		Narwhals	94	0	0	0	6	62	2.8 ± 3.4
	Lancaster Sound	Belugas[1]	44	8	7	2	39	122	4.1 ± 6.5
		Narwhals[2]	25	8	30	2	37	73	5.3 ± 9.9

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[1] Does not include a large herd of about 354 belguas that was moving south away from an icebreaker.

[2] Does not include 29 narwhals that were moving south toward the icebreaker.

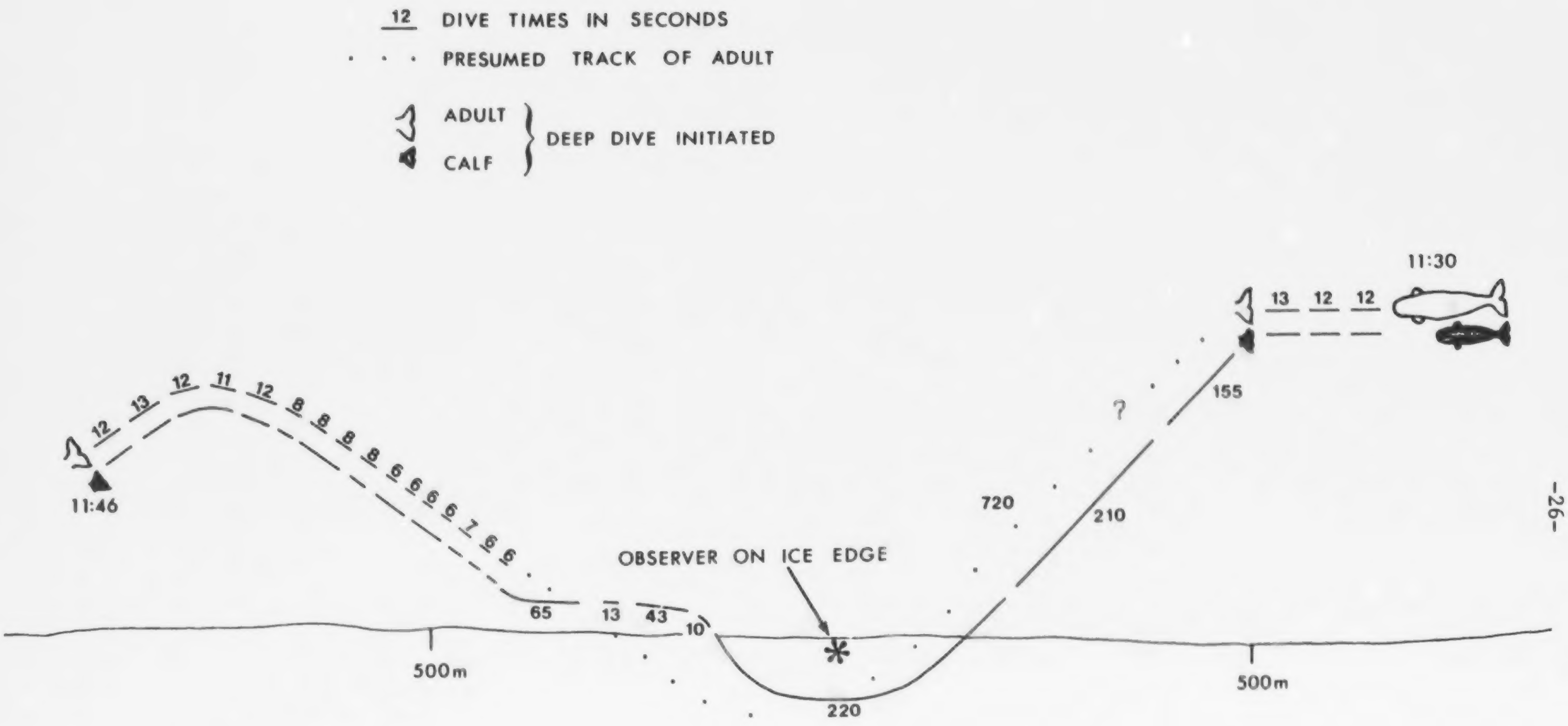
12 DIVE TIMES IN SECONDS
PRESUMED TRACK OF ADULT
ADULT
CALF
DEEP DIVE INITIATED
11:30
13
12
12
155
?
210
720
OBSERVER ON ICE EDGE
220
10
43
13
65
6
6
7
6
6
6
6
8
8
8
8
12
11
12
13
12
11:46
500m
500m

Fig. 9. Schematic representation of diving behaviour of an adult beluga and a subadult along the Admiralty Inlet ice edge between 11:30 and 11:46, 28 June. Distances are roughly approximated. Although the initial dive of the adult did not appear to be directed at the ice edge it is assumed that the subsequent orientation of the subadult reflected the adult's underwater position. After the subadult surfaced from beneath the ice to the west of the observer it moved strongly westward and, after its last dive of 65 s, surfaced beside the adult, moving away from the ice edge. The adult then undertook a series of 16 short dives, mostly in synchrony with the subadult, and was last observed as it initiated a deep dive toward the ice edge. Surfacing times were less than 1 s.

Table 4. Number of call types per minute by odontocete whales and other marine mammals recorded at the Admiralty Inlet ice edge, 27 and 28 June, 1982. (See Appendix B for a description of call types.)

	Number of calls/min on 27 June at					Number of calls/min on 28 June at				
	12:00	14:00	16:00	18:00	20:00	08:00	10:00	12:00	14:00	16:00
Tonal										
constant	21	14	11	35	22	4	8	8	4	18
shifted	3	2	1	12	8		1	3	1	2
undulating long	3			8	7		1			
undulating rapid	7	9		7	1	1			1	1
irregular	1	10	3	2	5		1	3		
Sweep-frequency										
s.f. 1										3*
2										4*
3					2					3
4		8	7	1					4	
5	4	1								
6		1	2							
7				2						
8				1						
9				8	1					
10				1	1				3	
11		1			1					
12		1								
13	1	1								
14	2									
15		3								
s.f. hybrids		1	1	3					1	3*
s.f. other		1		1						
Complex										
c. 1	1	1								
2									1*	
3									2*	
4				1						2*
5			1	1					3	3
6		1								
7							5			
8									1*	
9								1		
10										6*
11	1									
12										1
c. other										1*

Continued...

Table 4. Continued.

	Number of calls/min on 27 June at					Number of calls/min on 28 June at				
	12:00	14:00	16:00	18:00	20:00	08:00	10:00	12:00	14:00	16:00
Pulsive										
p. 1										2*
2							1			
3	1								2	
4	1									
5									1*	
6									2*	
7									2*	
8									3*	
9	2									
10						14	2	2		
p. other						2	4		2*	
Miscellaneous										
m. 1										
2		1						4		
3			1							
m. other	5						1			
Total # odontocete calls	53	56	27	83	48	21	24	21	33	49
Click series	3+	6+	30+	0	19+	5+	0	0	40+	0
Other calls										
ringed seal				2	1	1				
bearded seal	11	10	12	8	10	5	2	4	0	0
walrus					1					
unknown				2	2					

* Call types unique to the disturbance period.

** Minimum number of series detectable.

Bearded seal calls were frequent and often overlapping in all recorded samples, ranging from 8-12/min (Table 4). Other sounds included ringed seal 'chirps', the 'bell' sound of a walrus and low-frequency (0.2 kHz), paired 'oog-oog's from an unknown source.

Disturbance Period

Received Noise Levels

Open Water

The spectra of received noise levels at 12:15 on 28 June are presented in Figure 10. Animal calls still dominated the ambient noise but a small peak at 206 Hz was present. Later measurements indicate that this frequency was the same as a very strong tone emanating from the MV Arctic. The tone at 206 Hz in Figure 10 was not audible to the human ear. The ship was about 105 km from the hydrophone at this time.

At 14:31, the MV Arctic was 46 km (25 n.mi.) from our hydrophones. The ships was just beginning to work its way through a small ice field. The ship was plainly audible on the hydrophone with the sound quality reminding one of ventilation fans or blowers. The received level of the 205 Hz tone was 80.5 dB//1 μPa, and tonal peaks at lower frequencies were probably also due to the ship (Fig. 11). [Note that tonal peaks on the graphic spectra must be corrected for band width to indicate true levels.] Animal sounds continued to be strong and dominated the higher frequencies.

The received noise levels at 16:11 are shown in Figure 12. The ship was approximately 20 km away. Received levels were higher (about 5 dB) than at 14:31 (Figs. 11 and 12; Tables A-8 and A-9). The largest difference was at very low frequencies; the level in the 10-20 Hz band was 87.5 dB//1 μPa at 16:11 compared with 69 dB at 14:30.

At 16:56.5, the ship was advancing toward the ice edge at 15 knots at a distance of 6.4 km, as determined by radar. The wind was calm. Received noise levels (Fig. 13) were substantially higher than at 16:11 (20 km

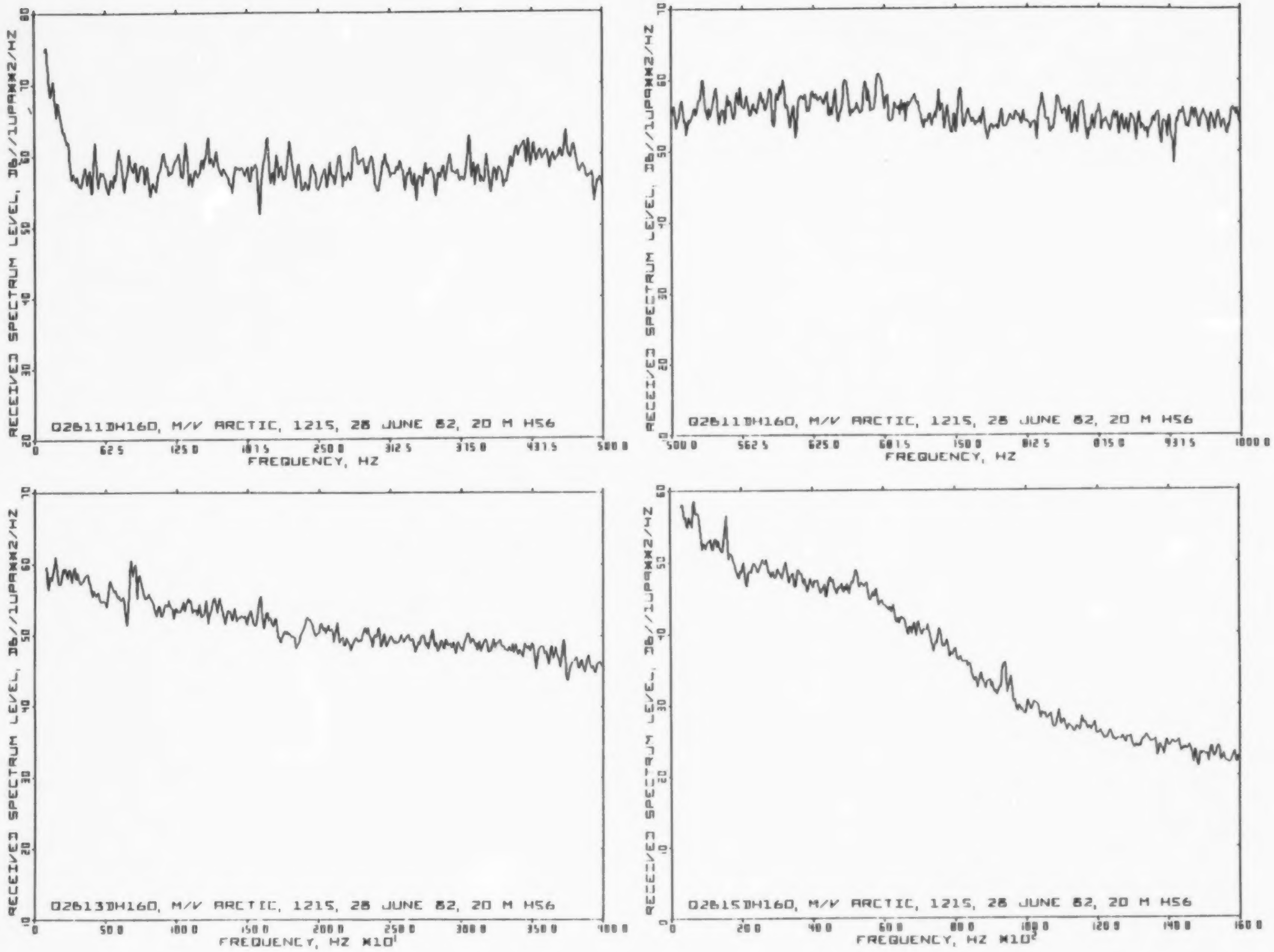

Fig. 10. Ambient noise spectra at 12:15, 28 June.

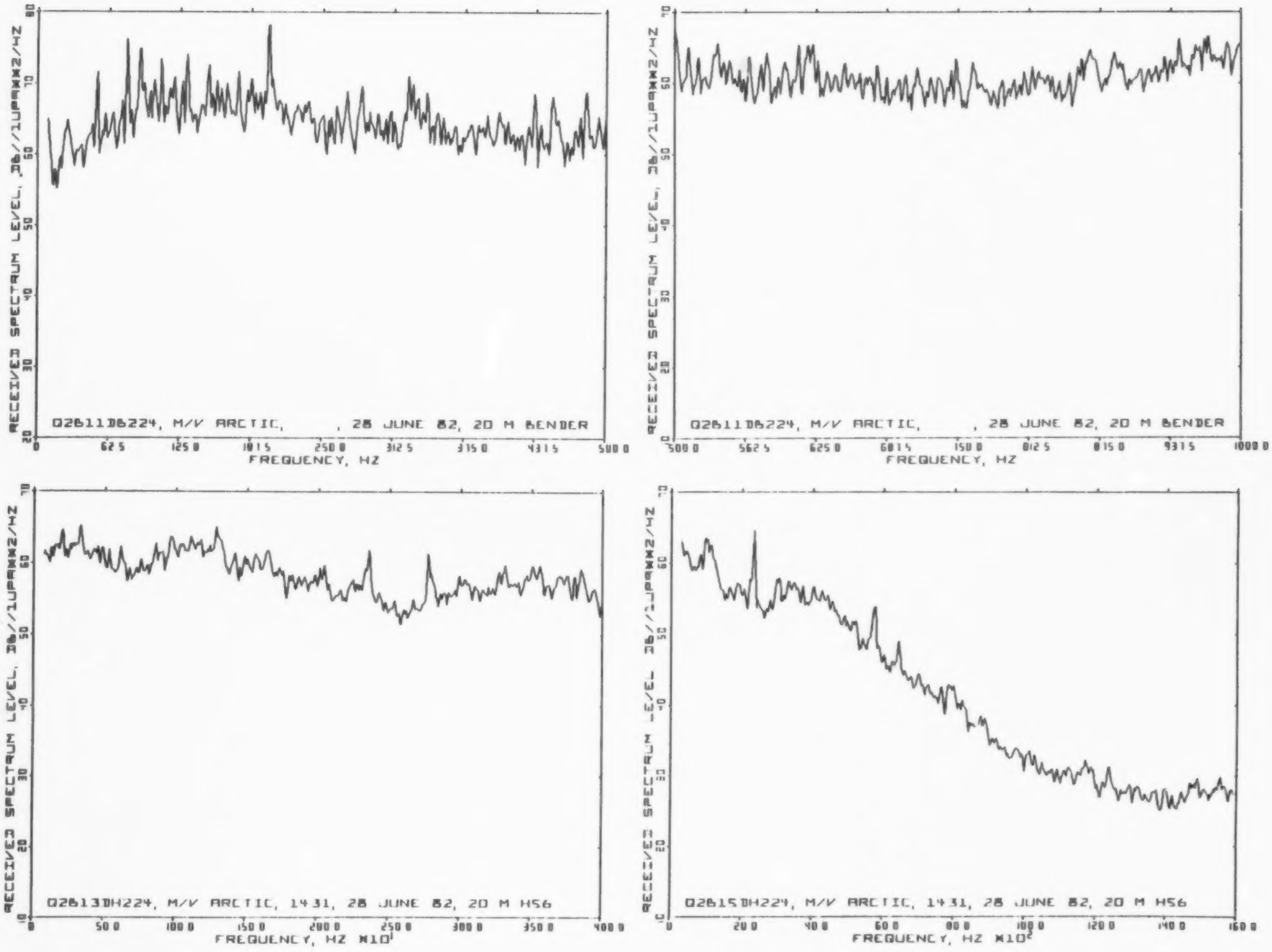

Fig. 11 Noise spectra at 14:31, 28 June.

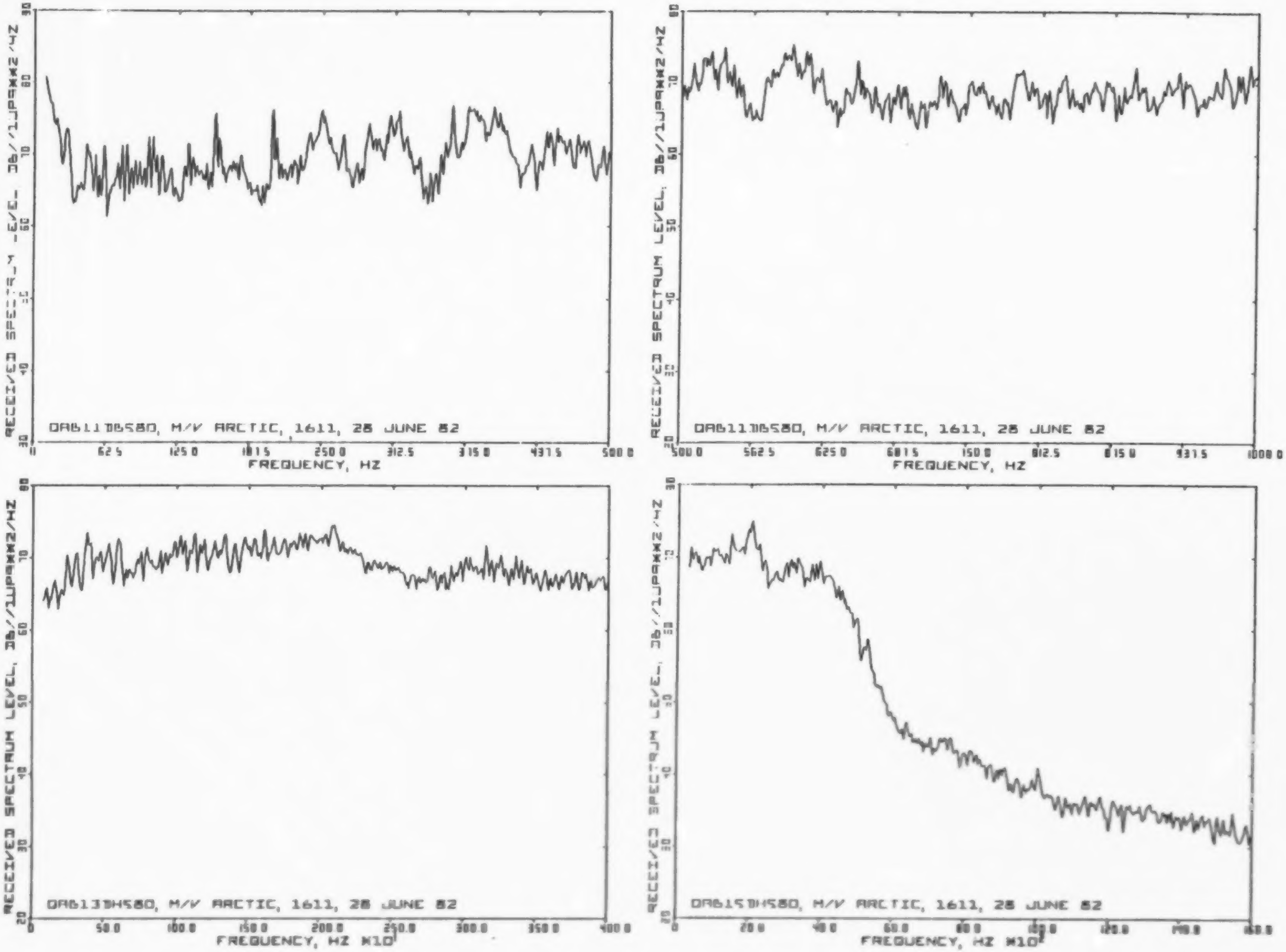

Fig. 12. Noise spectra at 16:11, 28 June.

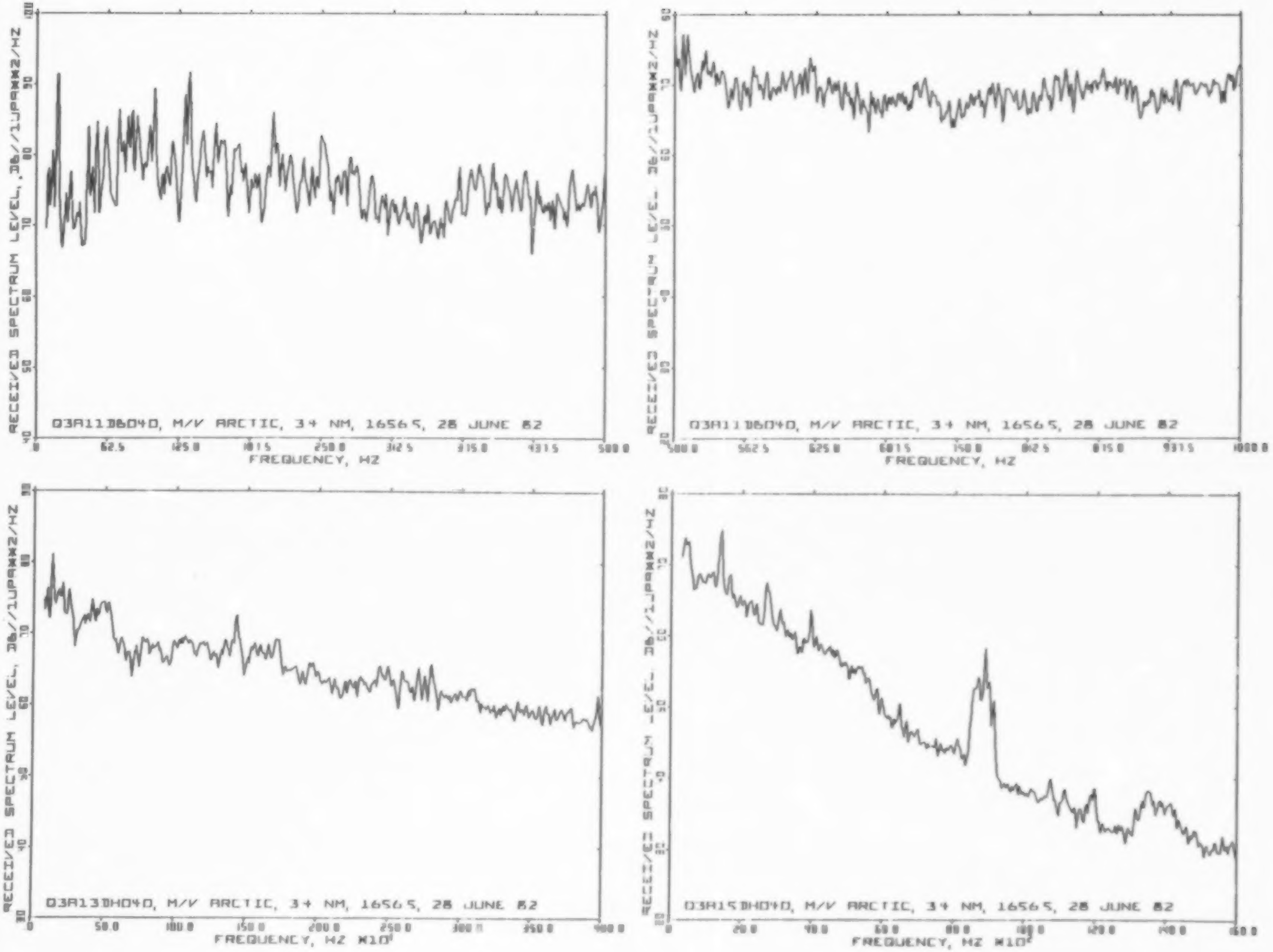

Fig. 13. Noise spectra at 16:56, 28 June.

distant). For example, in the 10-500 Hz band, the level at 6.4 km was 105 dB//1 μPa as opposed to 97.6 dB at 20 km (Tables A-9 and A-10). Animals could still be heard at the higher frequencies; the peak around 9 kHz (Fig. 13) was due to whale calls.

The ship was 2.9 km from the hydrophones at 17:05 and it had begun to slow down. Ship noise completely dominated the sound field and animals could not be heard (Fig. 14). The closely spaced peaks below 300 Hz were at intervals of 7 Hz. The rolling appearance in the low-frequency spectrum (with broad maxima at about 60 Hz, 150 Hz and 250 Hz) probably comes from multipath interference involving bottom reflections. The band level of the noise in the 10-500 Hz band had increased to 115 dB//1 μPa (Table A-11).

One of us (CRG) listened to the continuous recording with the low-frequency noise (below 2 kHz) filtered out. The last animal calls (whales) were heard at 17:02.

Ice-breaking

At 17:15 the MV Arctic was breaking ice just before stopping to pick-up a field party. The ship was 463 m (0.25 n.mi.) from the hydrophones. Noise levels had increased substantially (Fig. 15); the band level of the noise in the 10-500 Hz band was 127 dB//1 μPa (Table A-12). This level was about 38 dB higher than the highest natural ambient noise recorded on 27 or 28 June. Significant tonal peaks (113 to 116 dB) in the ship noise occurred at 15, 53, 111, 134 and 206 Hz. A higher frequency peak at 558 Hz was at 104.8 dB. [Again, note that spectrum values for tones on Figure 15 must be corrected for analyzing bandwidth to yield proper noise levels.] The increased noise level extended to the higher frequencies; the spectrum level at 16 kHz was about 65 dB//(1 μPa)^2/Hz. Audibly, CRG could not discern any distinctive changes in the ship noise when the ship entered the ice.

The ship was stopped at 17:16 and although noise levels were reduced, they remained relatively high (Fig. 16). The band level noise for the 10-500 Hz band was 120 dB//1 μPa (Table A-13). Machinery noise on the ship continued and we assume that the shaft and propeller continued to rotate, although in a neutral pitch position.

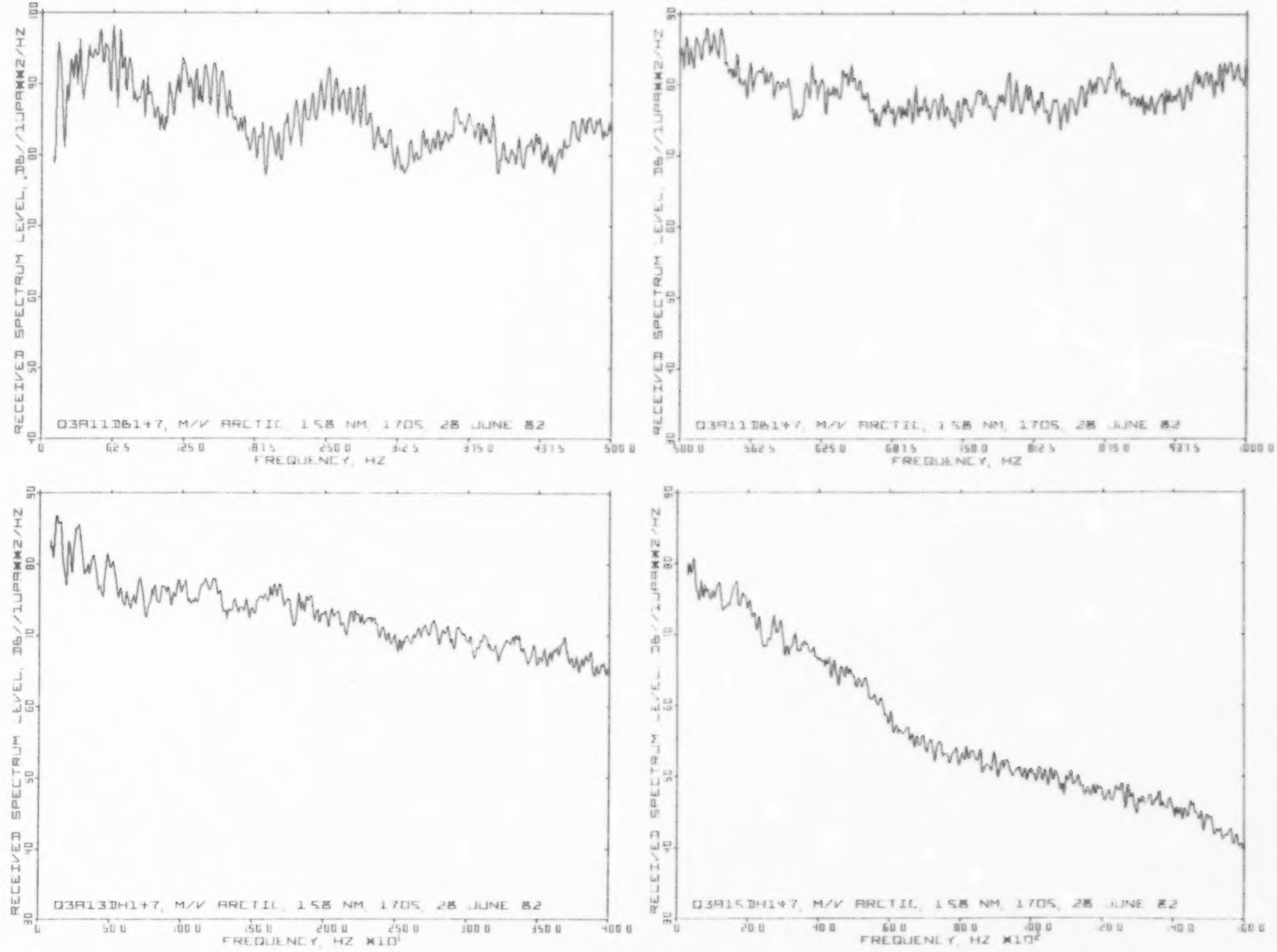

Fig. 14. Noise spectra at 17:05, 28 June.

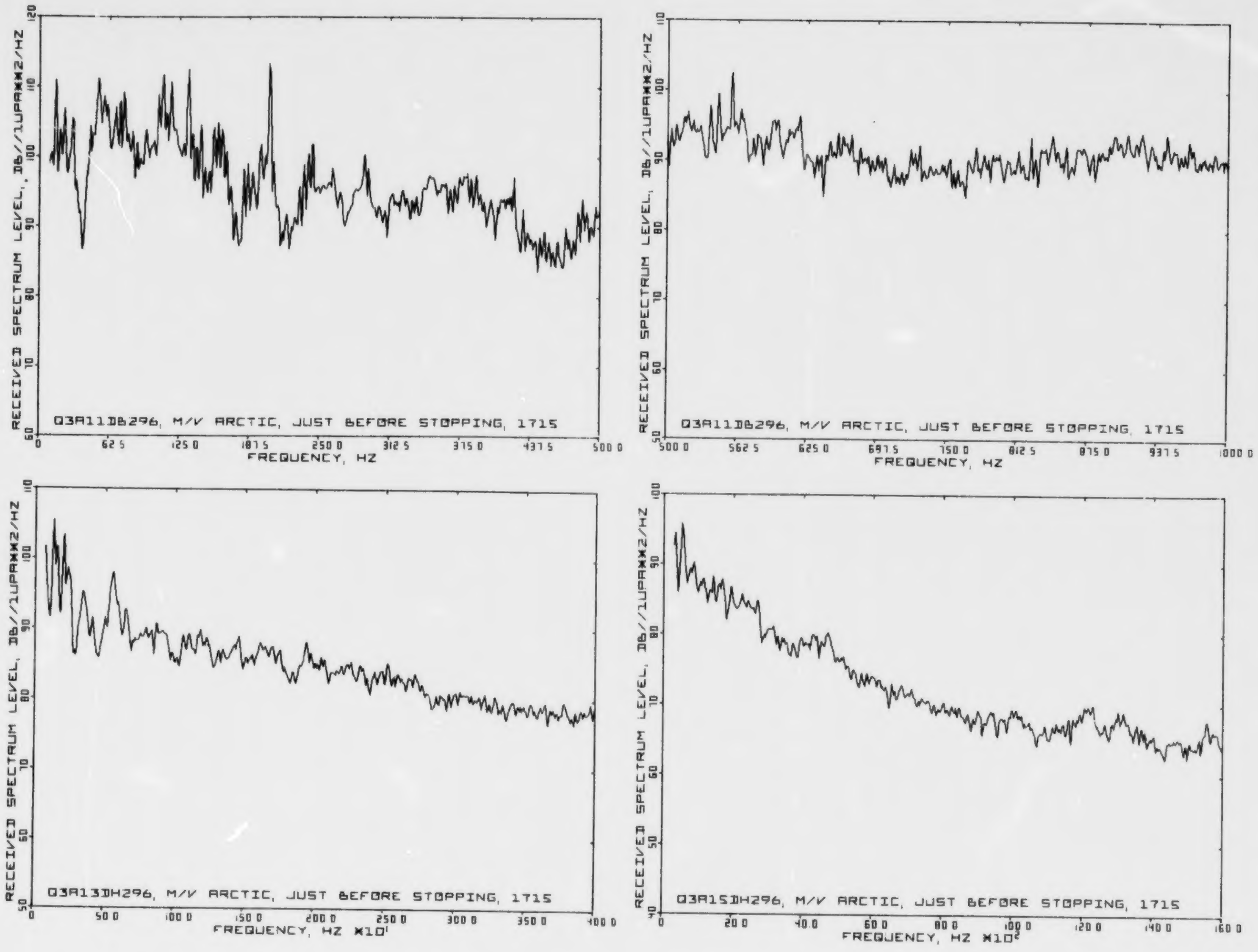

Fig. 15. Noise spectra at 17:15, 28 June.

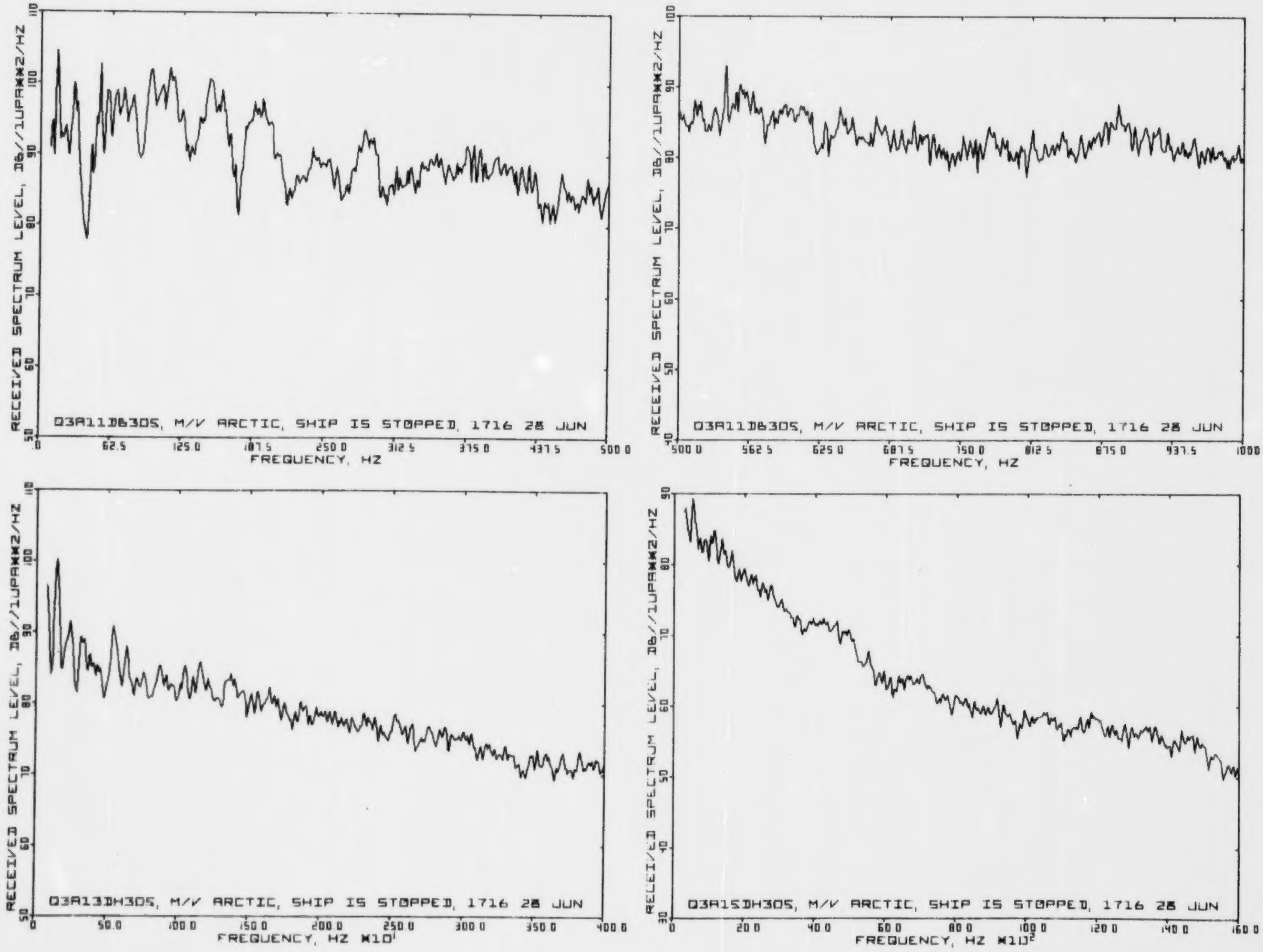

Fig. 16. Noise spectra at 17:16, 28 June.

The ship was stopped for about 30 min. It then began to back down prior to moving forward to ram the ice. Figure 17 presents the noise spectra received during this exercise while the ship was 463 m (0.25 n.mi.) distant. The noise level in the 10-500 Hz frequency band was 135 dB//1 μPa (Table A-14). This level was about 8 dB greater than that when the ship was moving forward at the same range. In general, noise levels were higher when the ship was going astern than when it was moving forward (see later section on Ship Source Levels). Typically, the MV Arctic spent about 4 to 6 min going astern before moving forward to ram the unbroken ice and pass through it. The forward movements continued until the ship was stopped by ice. The forward movements usually lasted longer than 4 to 6 min. The two-phase process was then repeated. Ice lined the sides of the ship at all times.

At 17:49, the ship was abeam of our camp with its propeller at its closest point of approach (CPA); the range was 463 m (0.25 n.mi.). The ship was ice-breaking in the forward mode. The received levels were high (Fig. 18). Levels in the 10-500 Hz band were 133 dB//1 μPa (Table A-15). The analysis of tones (not shown) revealed strong tones at 53 Hz (124 dB//1 μPa), 205 Hz (125 dB) and 812 Hz (110 dB). Spectrum levels at the high frequencies were substantial--about 70 dB//(1 μPa)^2/Hz (Fig. 18).

A distinctive pattern of ship noise was found during the ice-breaking cycle. Noise levels increased when the propeller pitch changed from reverse to forward thrust (Fig. 19). There was always a lull between the noise from going astern and the transition noise depicted here. The sound was what one would imagine the ship to sound like when the thrust is changed and the ship shudders heavily, especially in the after sections over the propeller, when the forward thrust works to reverse the direction of travel. We could hear the sounds of heavy metal plates vibrating severely. The band level for 10-500 Hz was 138 dB// 1 μPa (Table A-16), the strongest that we recorded. This transition from going astern to going ahead generated by far the strongest sounds; going astern itself generated the second strongest sounds, and going ahead was third. The transition event was also the shortest in duration, lasting on the order of 5 s. The source levels for these three modes are discussed in a later section.

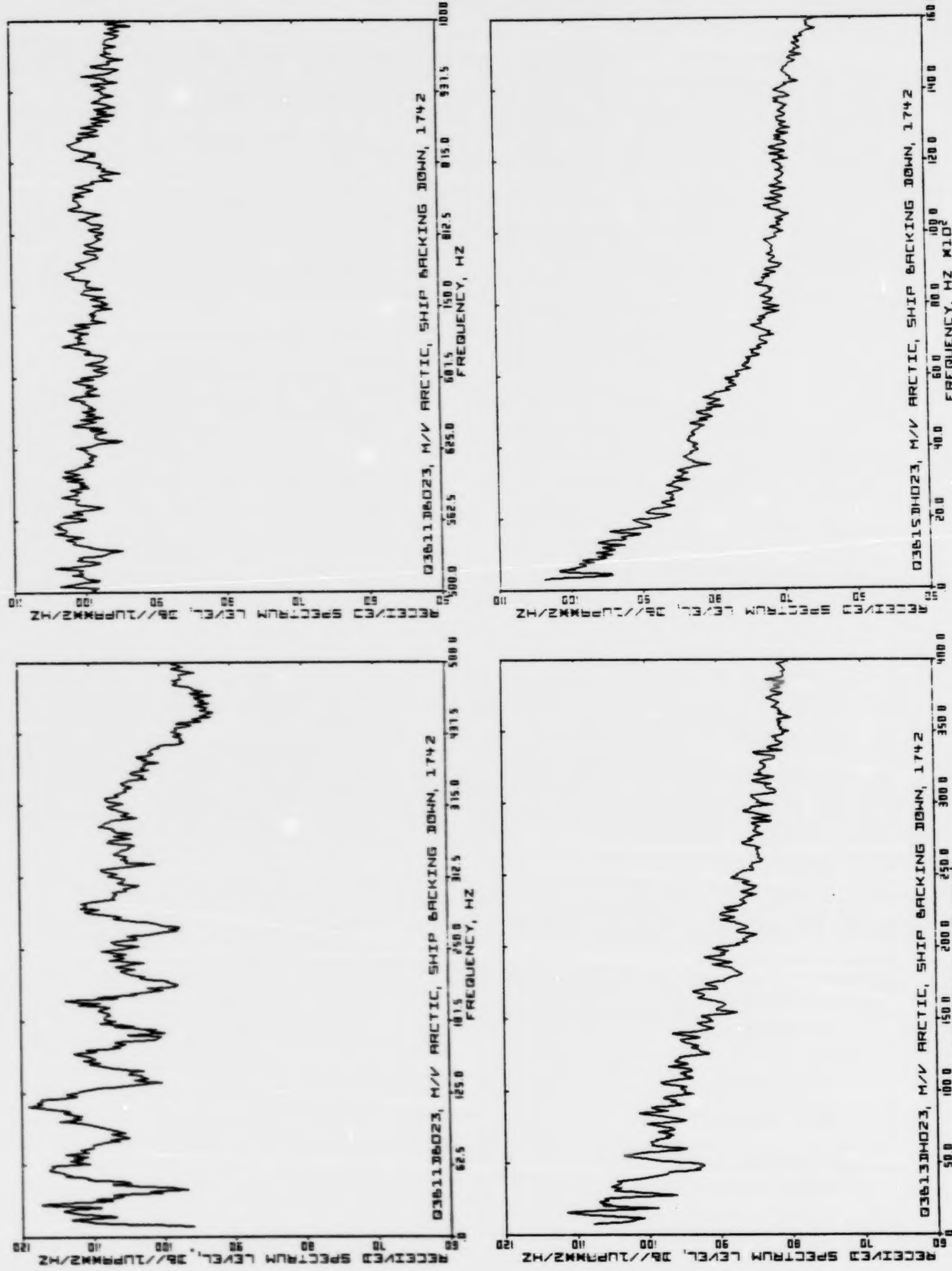

Fig. 17. Noise spectra at 17:42, 28 June.

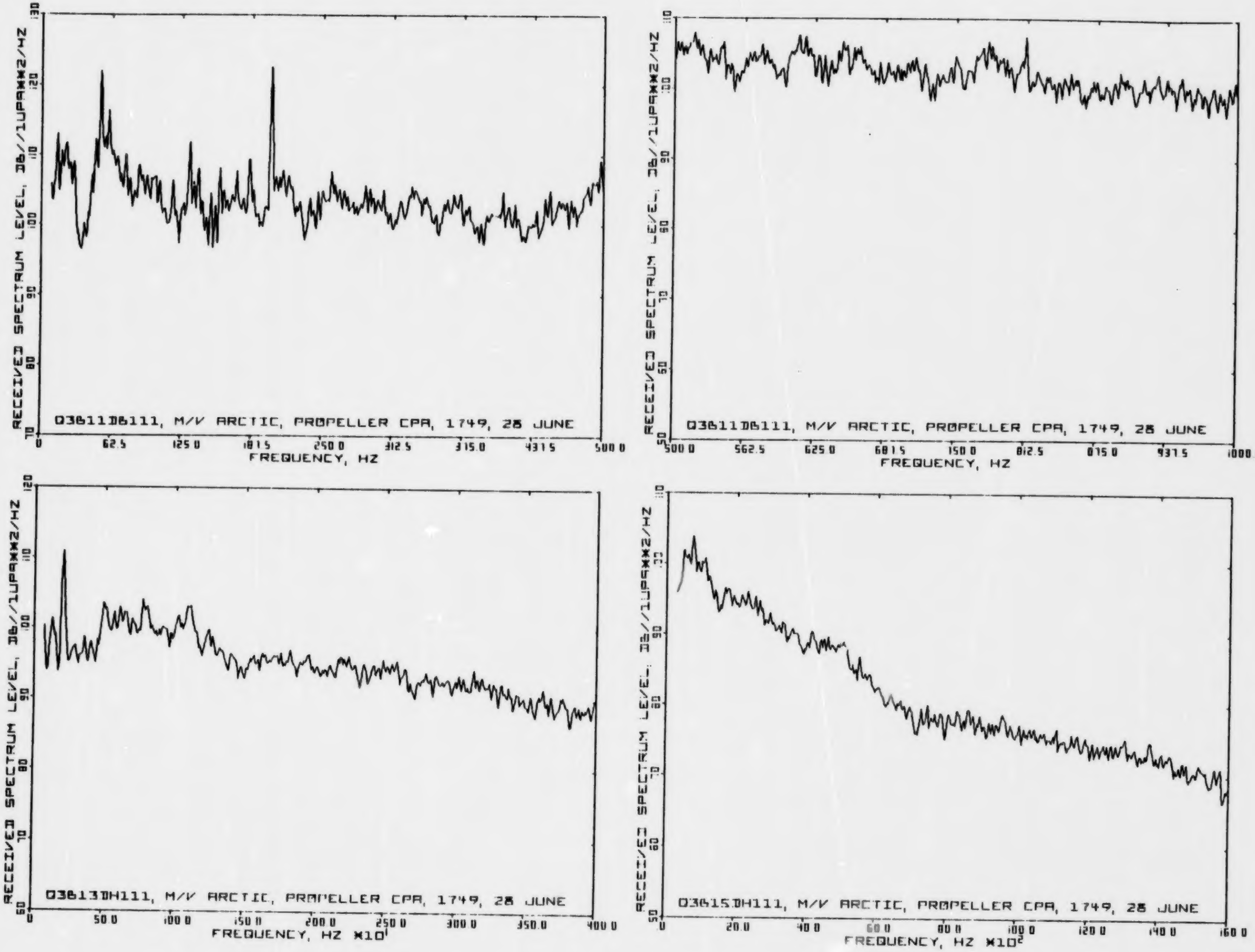

Fig. 18. Noise spectra at 17:49, 28 June.

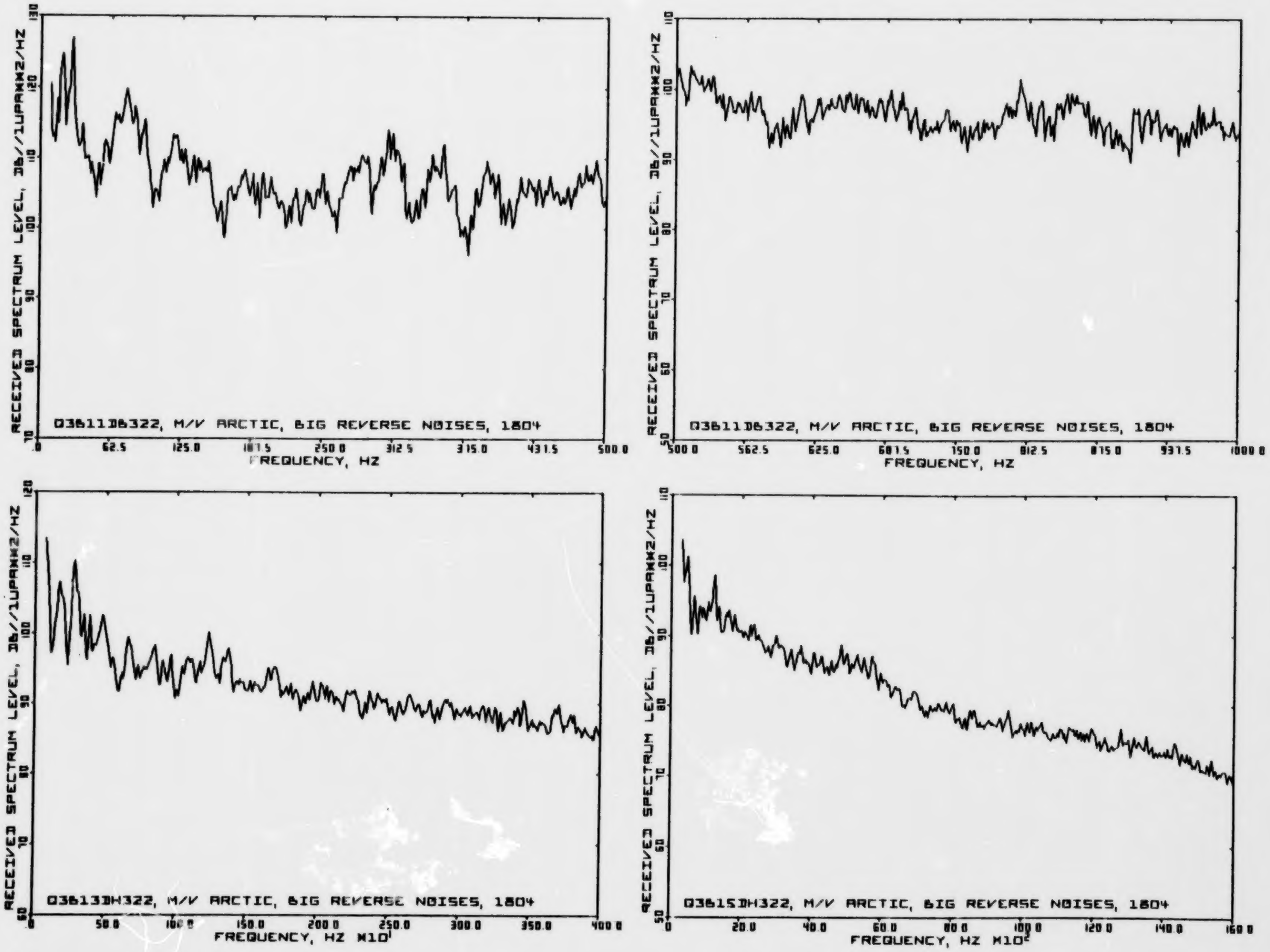

Fig. 19. Noise spectra at 18:04, 28 June.

Figures 20 and 21 show representative received levels when the MV Arctic was going astern and ahead at a distance of 4.8 km from our recording station. The ship was icebreaking. These figures illustrate the lower noise levels associated with forward as opposed to reverse movements. Levels in the 10 to 500 Hz band were 117 dB//1 µPa in forward movement and 127.5 dB in reverse (Tables A-17 and A-18).

At 23:00 on 28 June, the ship was about 7.5 km into the ice. By 09:05 on 29 June, it was 19 km into the ice. Bearded seals were first heard, after the ship passed the camp, at 09:30 on 29 June when the ship was about 20 km into the ice. Figure 22 presents the noise levels at 11:13 when the ship was moving forward about 21 km from the recording camp. The 205 Hz tone was the dominant ship noise and the band level in the 10-500 Hz band was 103.7 dB//1 µPa (Table A-19). The spectrum levels at higher frequencies were similar to the ambient noises before the ship arrived off Admiralty Inlet. For example, the level at 16 kHz was about 25 dB//(1 µPa)^2/Hz.

At 07:00 on 30 June, the ship was 41 km from the ice camp. Figure 23 presents the received noise spectra at 11:04 on 30 June when the forward-moving ship was about 45 km away. The received levels were relatively low, although the ship was still distinctly audible. Also, animal sounds are again clearly evident in the noise spectra.

By 15:00 on 30 June, the ship could only be heard at our camp when it was in reverse. Soon after, it turned into Strathcona Sound and could not be heard at all. The direct transmission path between the ship and our hydrophones was eliminated when the ship turned into the sound.

Transmission Effects

The water depth at the entrance to Admiralty Inlet is about 340 m. Although not shallow, the depth is shallow enough for bottom-reflected sound to interfere with direct-arriving sound and cause constructive and destructive effects on a frequency-selective basis. Some of the figures manifest such effects. For example, the ambient noise spectrum in Figure 4

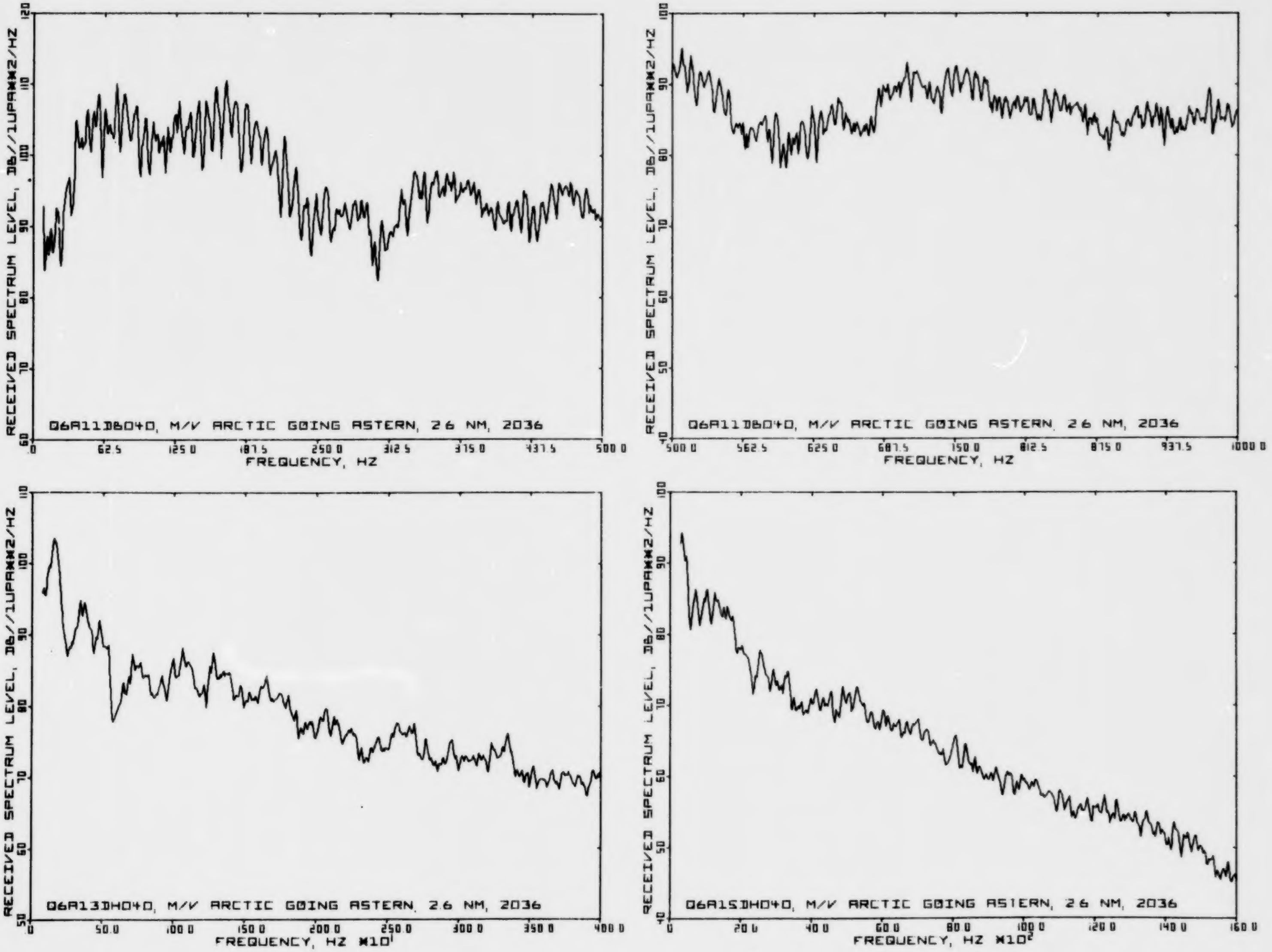

Fig. 20. Noise spectra at 20:36, 28 June.

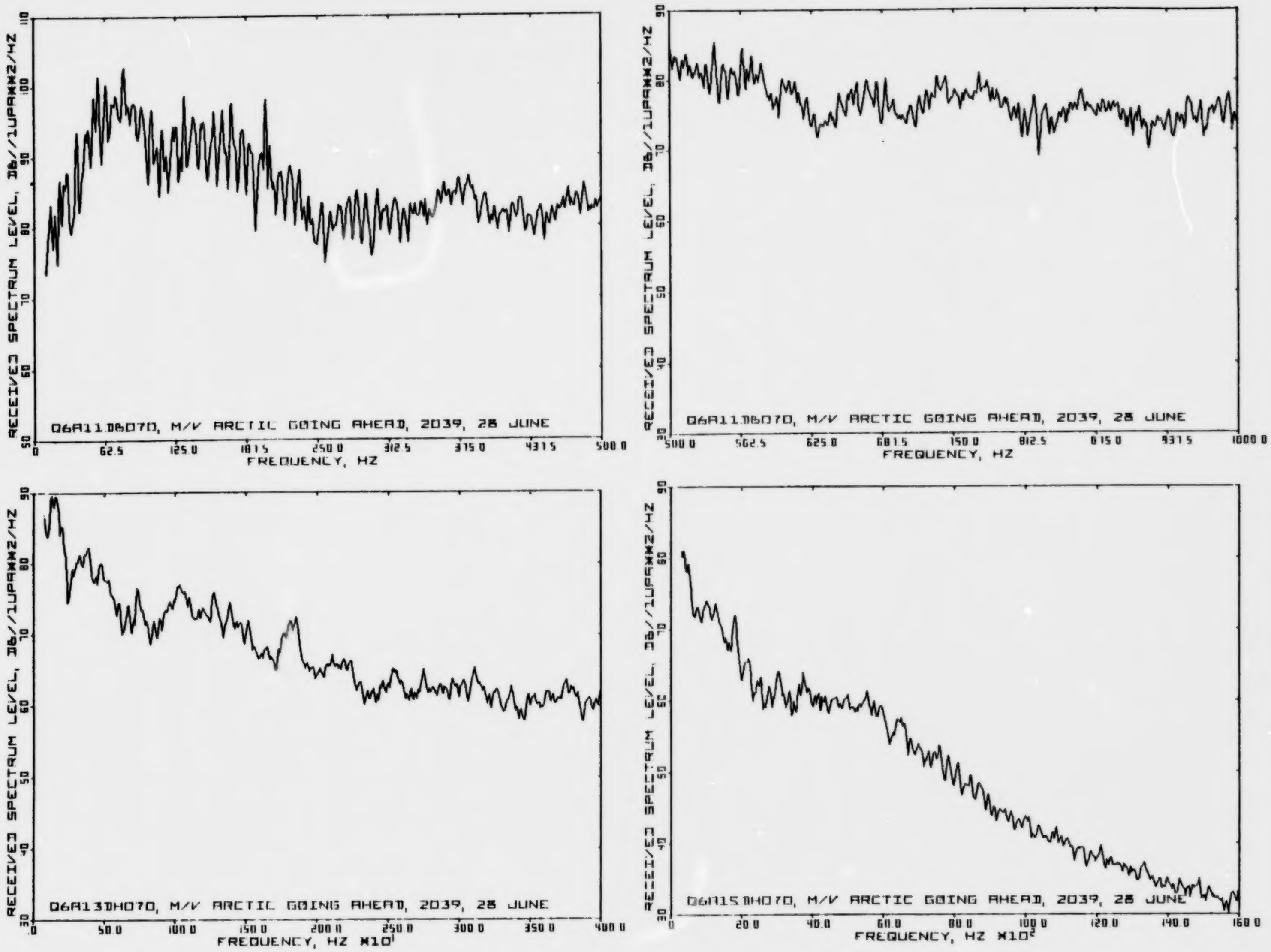

Fig. 21. Noise spectra at 20:39, 28 June.

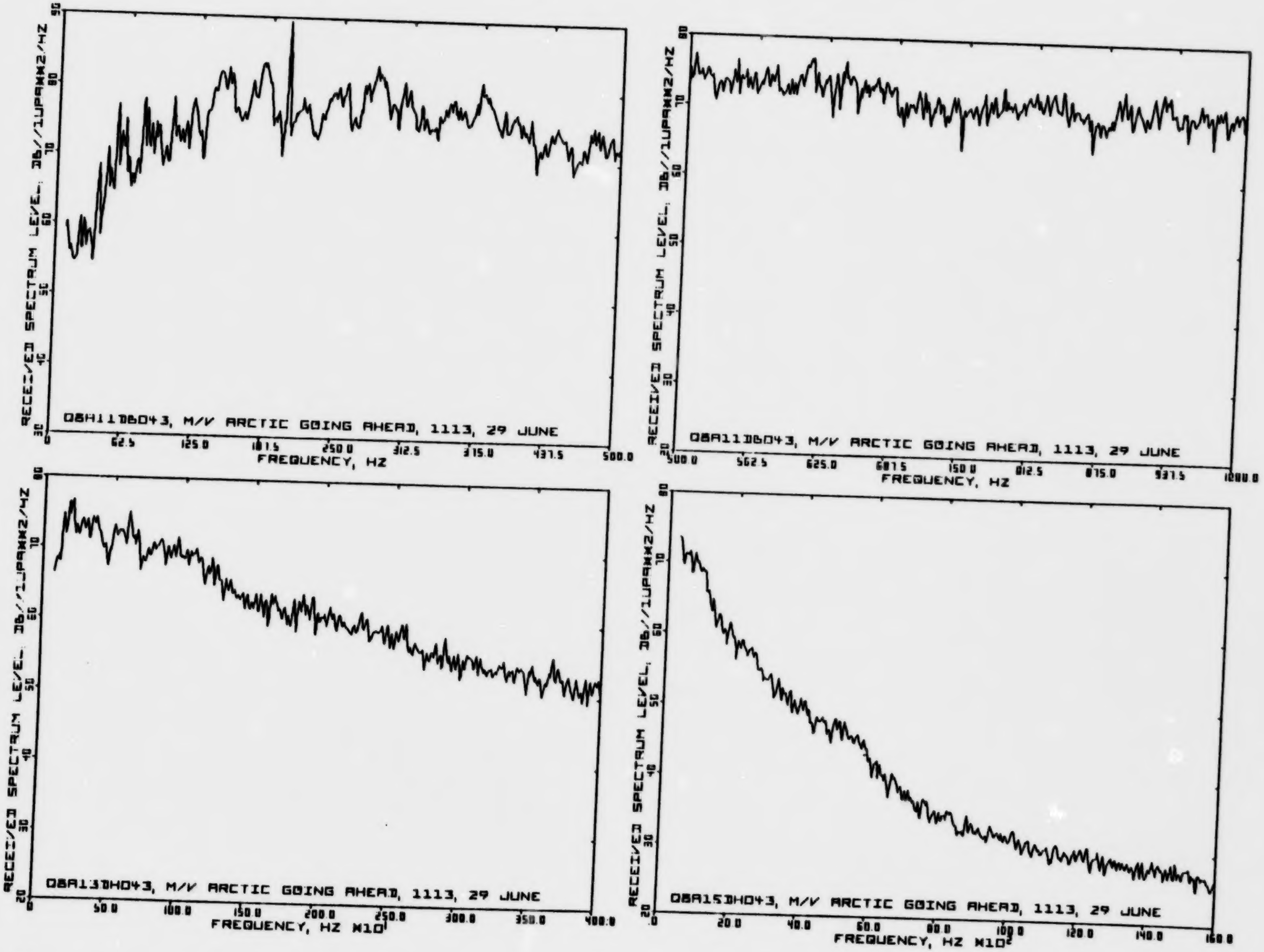

Fig. 22. Noise spectra at 11:13, 29 June.

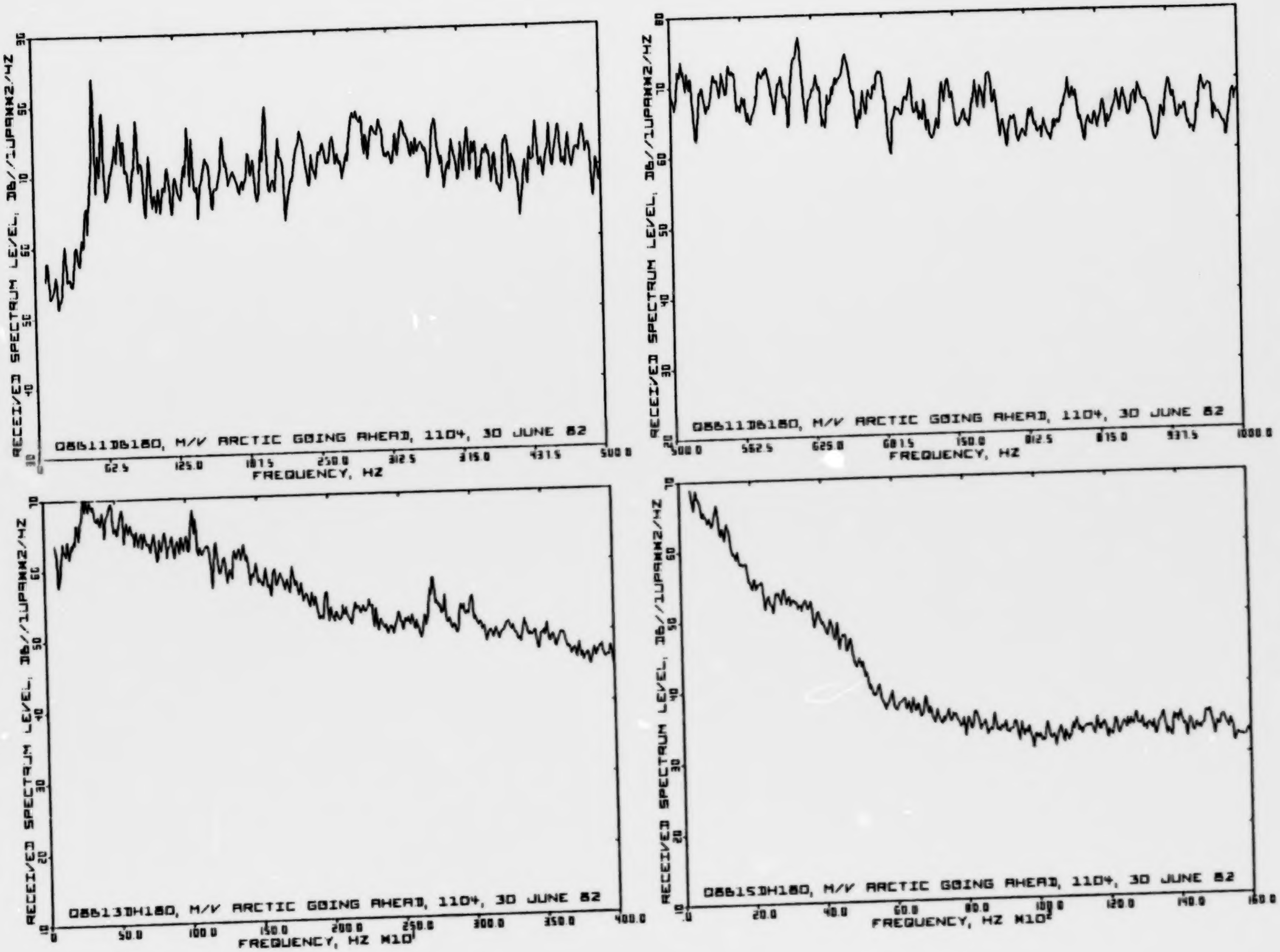

Fig. 23. Noise spectra at 11:04, 30 June.

shows a null in the levels around 30 Hz. Figure 16 (and many others as well) shows a variation in the spectrum level at the lowest frequencies, where the nulls occur at 40, 85, 126, 172, and 221 Hz. Reflected sound from the surface also contributes to these interference patterns and may even be more important than the bottom-reflected sound.

Effects of Receiver Depth

All of the above measurements were taken with the hydrophones at a depth of 20 m. At 16:08 on 28 June when the ship was about 20 km off the ice edge, the low-frequency bender hydrophones were deployed at depths of 20 m and 2.5 m (Fig. 24). As expected, because of the Lloyd Mirror effect, received levels at the hydrophone depth of 2.5 m were lower than at 20 m. The levels at 2.5 m were 7, 12, 12 and 11 dB//1 µPa lower in the octave bands 10-20 Hz, 20-40 Hz, 40-80 Hz and 80-160 Hz, respectively (Table A-21).

Similar measurements were made at 17:02 (Fig. 25) and 17:48 (Fig. 26) on 28 June. At 17:02, the ship was approaching the ice at a distance of about 4.1 km from our hydrophones. At 17:48, the ship was going forward and breaking ice at a distance of about 460 m. At 17:02, the received levels at the shallow receiver (2.5 m) were lower than at the deep receiver (20 m) by 13.2, 15.7, 11.1 and 3.1 dB//1 µPa for the bands 10-20 Hz, 20-40 Hz, 40-80 Hz and 80-160 Hz, respectively (Table A-22). The corresponding differences at 17:48 were less: 6.0, 7.4, 4.0 and 1.9 dB//1 µPa.

Whale Behaviour and Distribution

Sound from the MV Arctic was present on our tapes at 12:15 on 28 June when the ship was still about 105 km away in a straight-line distance (Fig. 10). The sound was not audible to the human ear. Whales were not observable from the ice edge at the acoustic camp at this time, although animal sounds continued to be strong on the underwater recordings. Two observation posts at the ice edge were manned from 12:00 onward on 28 June. The 'east' post was about 5 km east of the point where the ship would enter the ice edge, the 'west' post was 5 km to the west of the ship track.

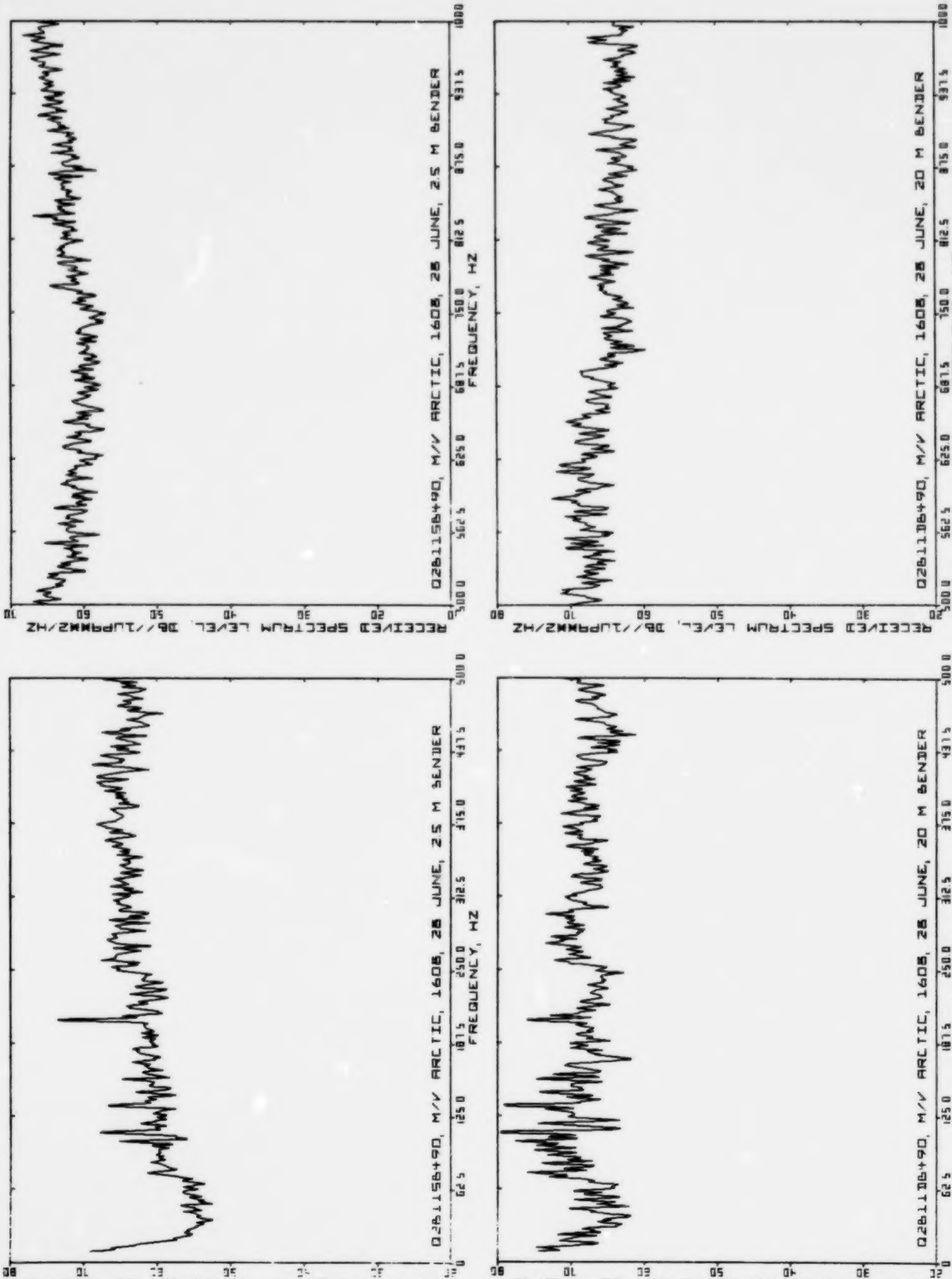

Fig. 24. Noise spectra at 16:08, 28 June.

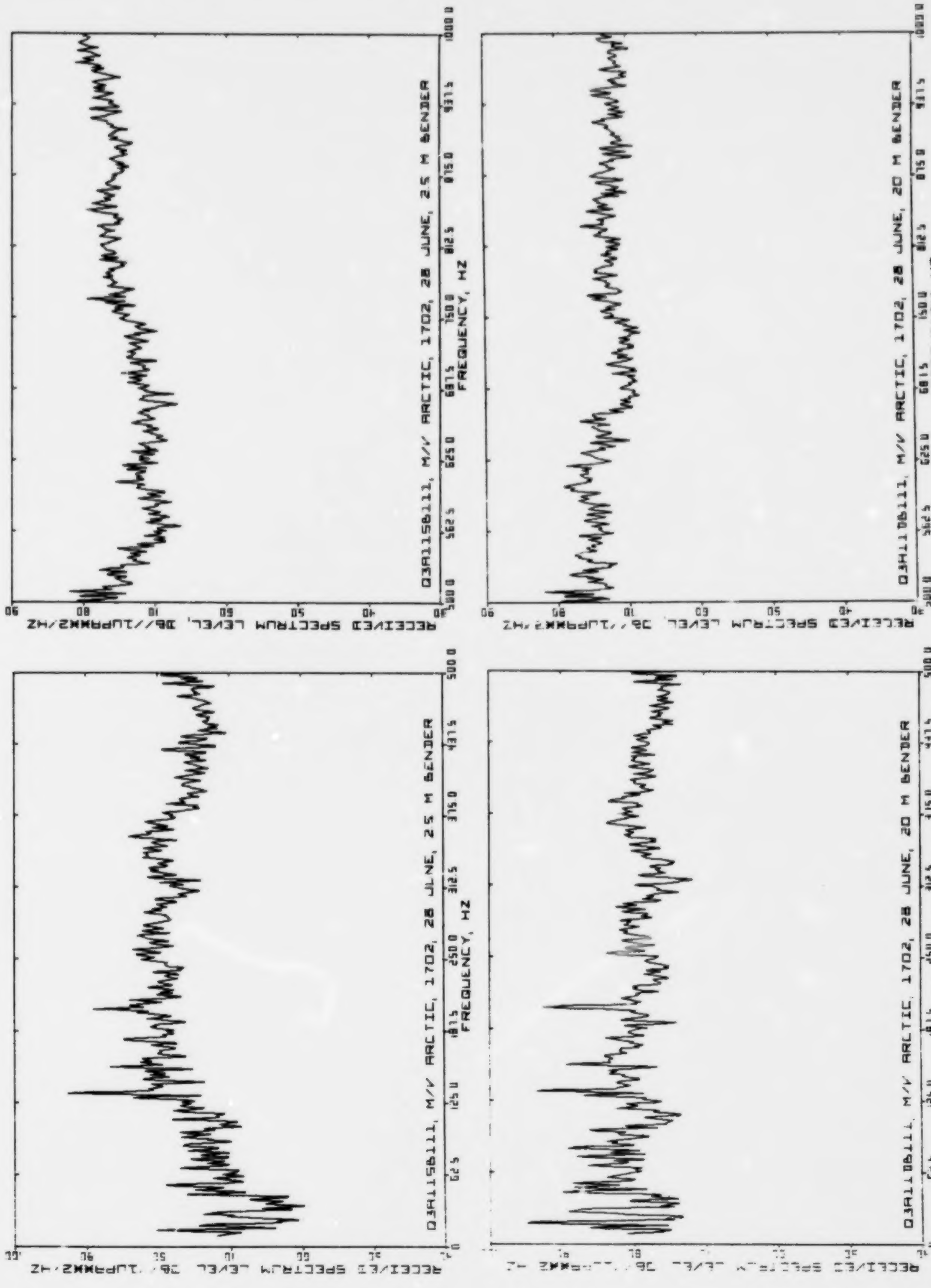

Fig. 25. Noise spectra at 17:02, 28 June.

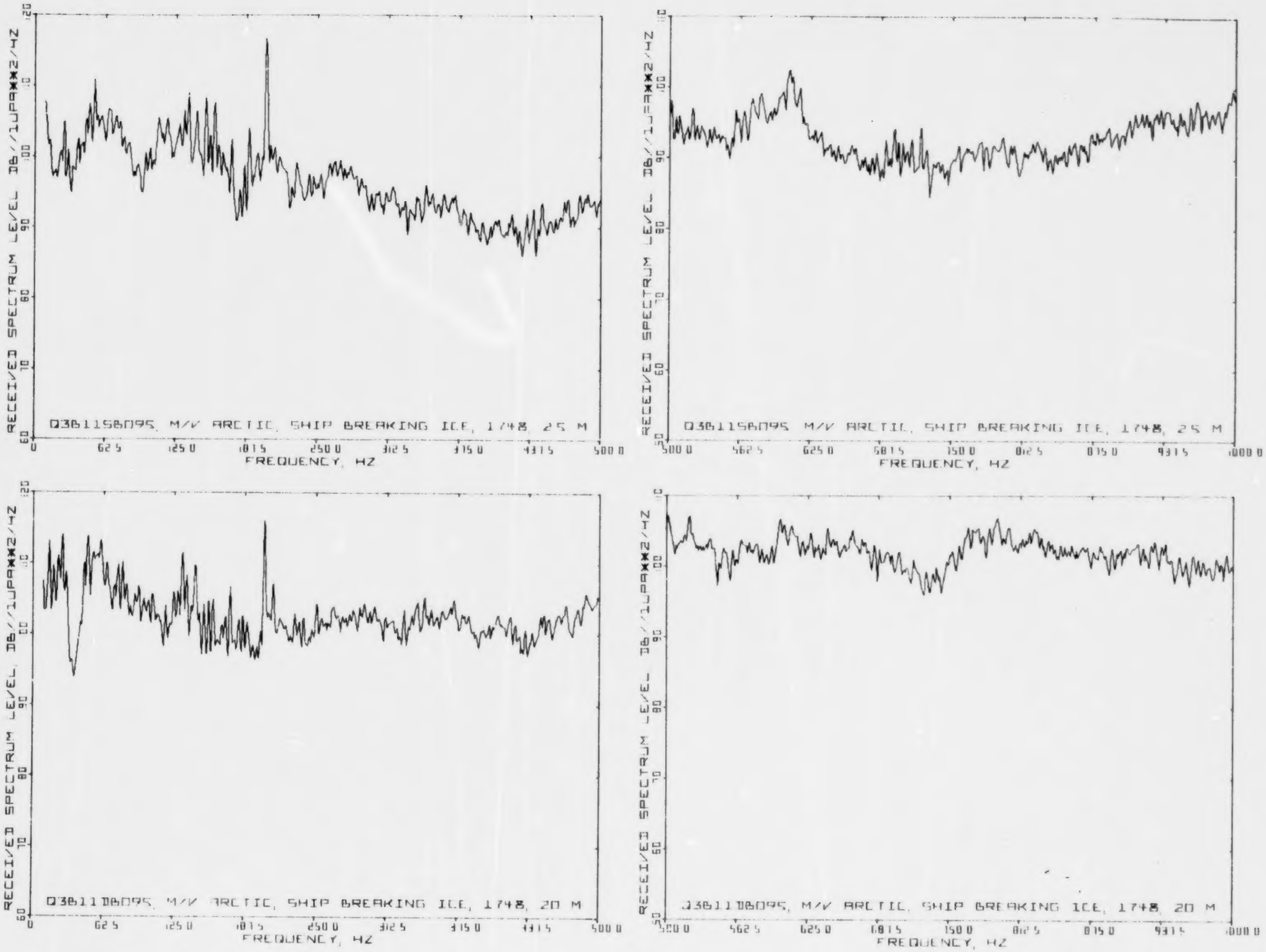

Fig. 26. Noise spectra at 17:48, 28 June.

Beluga

No whales were observed from these observation posts until 15:00 when observers at the 'east' post noted many belugas moving rapidly westward along the ice edge. This movement was detected by observers at the 'west' post at 15:18. Although the distance between the camps was only an approximation, it is probable that these belugas were travelling at speeds of over 20 km/h. Vladykov (1944) states that belugas can attain speeds of 14-18 km/h when being chased and Davis and Finley (1979) reported that migrating belugas can sustain speeds of 12-14 km/h during fall migration. Clearly, the belugas along the Admiralty Inlet ice edge were moving very rapidly. The whales moved parallel to the ice edge. None was more than 150 m off the edge and most were within 20 m. Many whales dove under the ice. The bow waves created by their rapid swimming washed over the ice edge. The Inuit observers noted the heads of the belugas rose farther out of the water during this rapid movement than during normal swimming behaviour. The surfacing behaviour of individuals in pods lacked synchrony but this could not be quantified.

It was difficult to obtain an accurate count of the belugas during this westward movement since many were undertaking long dives beneath the ice edge. Some groups certainly travelled for more than 1.5 km beneath the ice edge and it is likely that we missed some. Observers at the 'east' post counted 213 belugas between 15:00 and 16:30 and observers at the 'west' post estimated that at least 300 belugas passed by between 15:18 and 17:00. Most of the herd was comprised of females attended by subadults of various ages; few unattended adults or 'bachelor' pods were seen (Table 3). Only one (possibly two) neonatal calf was identified.

After 16:25, the behaviour of the belugas changed noticeably. Observers at both observation posts noted independently that some of the belugas began to move away from the ice edge toward a band of brash ice. Observers at the 'east' post noted that the westward movement slowed markedly. At 16:34, the first eastward movement by some individuals was noted. The ship was 12 km from the ice edge at this time. From 16:34 to 17:09 the movement patterns of the belugas appeared confused, with animals moving in both directions, frequently turning, milling, and diving beneath the ice edge.

Between 17:07 and 17:09, with the ship less than 2 km from the ice edge, three pods of belugas, consisting of 4 adults, 2 adults, and 2 adults with a subadult, passed the observers at 'east' post moving toward the icebreaker. At 17:10 these groups were observed moving east past the observers. All other groups (6 groups of 2, 1, 3, 2, 3, 2, individuals) seen between 17:10 and 17:25 were heading east but at a notably slower pace than the initial westward movement. It appeared that these whales had been 'cut off' from the major westward movement. The last groups of belugas seen at the 'west' post were moving rapidly westward at 17:31. Observations were continuous at both posts until 20:00 and intermittent afterwards. No additional belugas were observed.

Narwhal

Only three individual narwhals were seen at the 'west' post during the major westward beluga movement. However, between 17:00 and 18:00 narwhals were present at both observation posts. Thus, behavioural observations are available for the period when the ship approached and entered the ice edge. In one notable respect, the behaviour of the narwhals differed from that of the belugas. Whereas the belugas continued to move in a confused manner, the narwhals moved slowly, frequently becoming motionless close to the ice edge. In contrast to the forward-rolling dive characteristics of the belugas, the narwhals tended to sink quietly beneath the surface with little or no audible respiratory sound. Pods of narwhals were notably more cohesive than those of belugas.

A pod of 9-10 male narwhals, containing two distinctively scarred individuals, remained in the vicinity of the observers at the 'east' post from 16:34, as the ship approached the ice edge, until the ship had penetrated into the ice. From 16:34 until 17:07 this pod remained quietly against the ice edge in the same position about 400 m to the east of the observers. The pod disappeared as the ship entered the ice at 17:14 and four animals, thought to be from this group, reappeared briefly about 100 m east of the observers at 17:17, as the ship came to a stop. The entire group reappeared at 17:25 about 100 m west of the observers within 5 m of the ice and remained there for 60 s, facing the ice edge. One individual rolled on its side, raising its flipper from the water and brought it to rest on the back of another individual. A tusk was raised from the surface and placed obliquely across the back of another individual forcing it beneath the surface. The pod then sank quietly beneath the surface and reappeared after 150 s within 30 m of the observers and <5 m from the ice edge. They remained there 70 s, quiet, facing the ice edge. At 17:38, about 2 min before the ship started moving again, the narwhals sank beneath the surface and reappeared at 17:43, about 800 m to the east, facing the ice edge, as the ship was in full-forward, ramming mode. The pod was last observed at 17:58, about 100 m from the ice edge, moving slowly offshore. Again, an individual was observed lifting its tusk out of the water and bringing it down on the back of another.

In addition to the identifiable pod of 9-10 narwhals, the observers at the 'east' post saw three other pods consisting of 7, 7, and 6 individuals during the period from 16:34 to 18:00. The pod of six individuals, consisting of females and subadults, surfaced within 10 m of the ice edge and less than 20 m from the observers at 17:25 when the ship was at idle, and remained approximately 45 s before disappearing beneath the ice. They reappeared about 200 m to the east after about 60 s and continued moving slowly east. We did not resight any of the other pods.

The last narwhals seen at the 'west' post were moving rapidly westward at 17:31.

29 June

The 'east' and 'west' observation posts were manned on 29 June but no belugas or narwhals were present. A single bowhead whale was encountered at the 'east' post at 10:00 lying on the surface within 2 m of the ice edge. The bowhead dove and reappeared 5 min later about 2 km farther west along the ice edge. The animal continued west and disappeared.

Between 13:00 and 16:00, observers from the 'east' post scaled a hill at the east end of the ice edge. From a vantage point about 75 m ASL, no whales could be seen in eastern Admiralty Inlet.

Aerial Survey

An aerial survey of the ice edge was begun at 20:51 on 29 June. No whales were present along the Admiralty Inlet ice edge or along the coast to the northeast (Fig. 27). However, large numbers of belugas were present in nearshore waters along the north coast of the Brodeur Peninsula. A total of 767 belugas were counted during the first pass between Cape Crauford and the Lancaster Sound ice edge and 796 were counted on the return survey (Fig. 27). Except for two groups of about 250 belugas that were milling at the mouths of two small rivers, all other animals were widely dispersed in small groups within 2 km of the coast and all were moving strongly east toward Admiralty Inlet.

A portion of the Lancaster Sound ice edge was also surveyed. A total of 276 belugas, 118 narwhals and one bowhead whale were counted (Fig. 27). In contrast to the whales along the coast, the movements of the whales along the ice edge appeared casual, with animals moving both north and south parallel to the ice edge; some animals were facing or directing dives toward the ice edge (Table 3). Some pods of narwhals and the bowhead were immobile, resting close to the ice edge. There appeared to be a preponderance of adult narwhals and belugas among the whales along the offshore ice edge, whereas it was noted (but not quantified) that the coastal herds of belugas were comprised largely of adults attended by subadults (Table 3). On the return survey, about 1 h later, it was noted that the first groups of belugas had arrived at the Admiralty Inlet ice edge near Cape Crauford.

Whale Vocalizations

Vocal activity of whales on 28 June was reduced early in the day (17-24 calls/min) compared to the previous day and was comprised primarily of complex and pulsive sounds (Table 4). Tonal calls comprised 24-82% of the

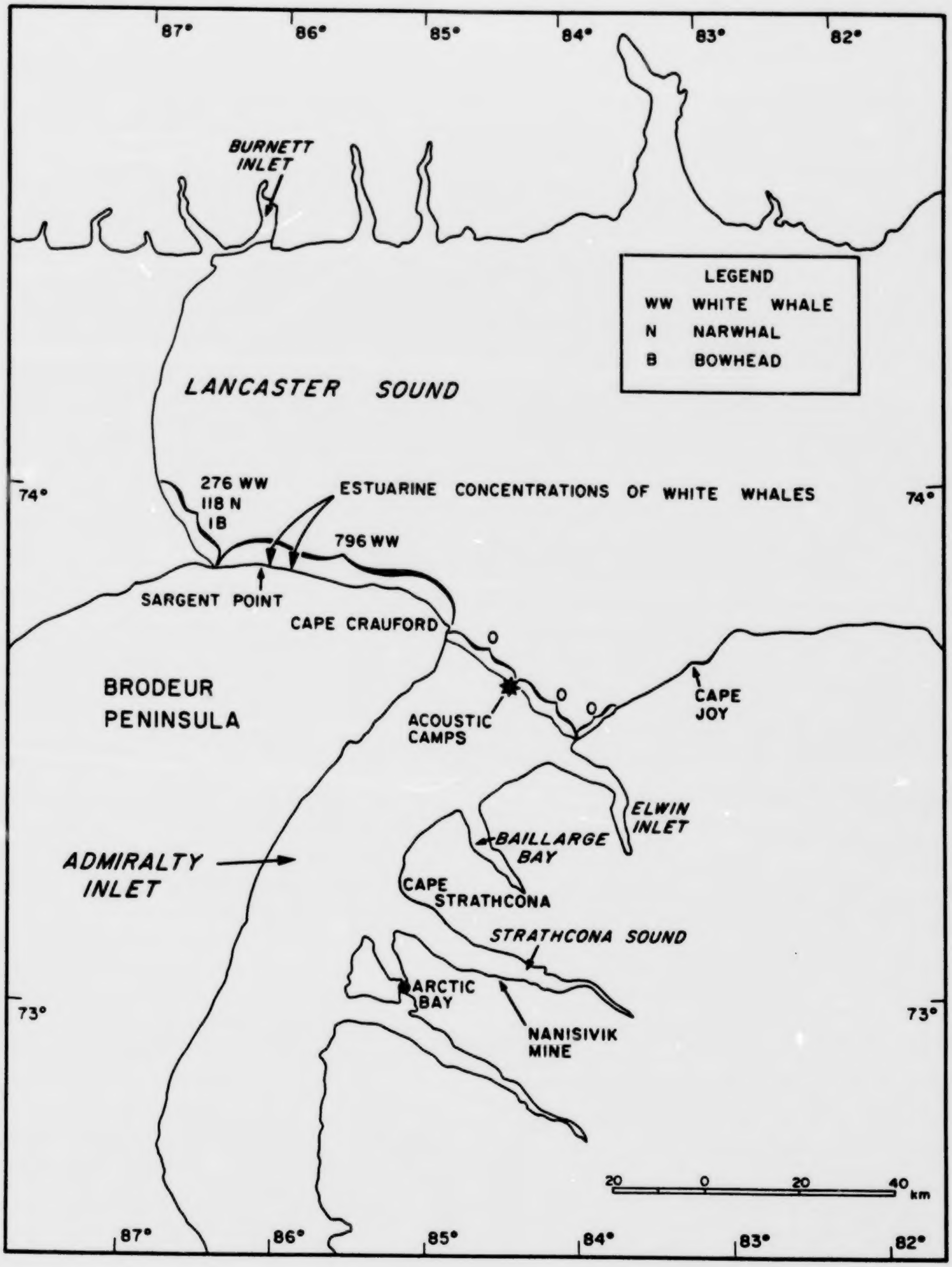
87°
86°
85°
84°
83°
82°
BURNETT INLET
LEGEND
WW WHITE WHALE
N NARWHAL
B BOWHEAD
LANCASTER SOUND
74°
74°
276 WW
118 N
1 B
ESTUARINE CONCENTRATIONS OF WHITE WHALES
796 WW
SARGENT POINT
CAPE CRAUFORD
BRODEUR PENINSULA
ACOUSTIC CAMPS
CAPE JOY
ELWIN INLET
BAILLARGE BAY
ADMIRALTY INLET
CAPE STRATHCONA
STRATHCONA SOUND
ARCTIC BAY
NANISIVIK MINE
73°
73°
20 0 20 40 km
87°
86°
85°
84°
83°
82°

Fig. 27. Distribution and numbers of narwhals, white whales (belugas) and a single bowhead whale along the Admiralty Inlet ice edge, adjacent coastal areas and part of the Lancaster Sound ice edge between 20:51 and 22:05, 29 June.

vocalizations during recorded segments at 08:00, 10:00 and 12:00 but sweep-frequency calls were absent in those segments.

A marked change occurred in the type and quality of whale calls recorded between 14:40 and 14:50, when the noise of the MV Arctic was distinctly audible to the human ear. Much more of the sound energy in the calls was in the higher frequencies (up to 12 kHz) and included a large proportion (58%) of distinctive complex (c.2,3,8; Appendix B) and pulsive (p.5,6,7,8, etc.) calls that were unique to this period (Table 4). The most notable aural quality was that of the broadband 'screams' (c.2,3) and the harsh rasping sounds (p.6,7,8). 'Click series' were numerous (40+) and strong during this period. These sounds were recorded 10 to 20 min before observers at the 'east' post saw the beginning of the westward movement of belugas and narwhals along the ice edge.

The recorded segment at 16:10 was again characterized by a large proportion (27%) of distinctive complex calls. Almost all of the tonal sounds were of the high-frequency t.1 type and most of the sweep-frequency calls were unique to this period (s.f.1,2, etc.; Table 4). Pulsive sounds were nearly absent and no 'click series' were detected, although the noise of the MV Arctic may have masked these sounds. At this point most of the belugas had passed by the acoustic camp and the MV Arctic was about 24 km from the ice edge.

Bearded seal calls were absent for the first time in the recordings taken at 14:40 and 16:10; they were absent until 09:30 on 29 June. They were infrequent (max. 2 calls/min) throughout the rest of 29 June when the noise of the MV Arctic predominated.

No whale calls were heard throughout 29 June until 23:00 when faint pulsive calls and at least nine click series (repetition rate 8.5 ± 1.8/s, n = 6) were heard above the background noise of the MV Arctic. At about this time (see previous section, Fig. 27) belugas were arriving at the Admiralty Inlet ice edge from the west.

Other Marine Mammals

During the period of icebreaking disturbance we also noted the behaviour of ringed seals (hauled out on the ice and swimming) and a single walrus. Near the 'west' post, a walrus remained hauled out along the ice edge throughout the disturbance period, and when the ship struck the ice 5 km away the walrus remained sleeping. It remained hauled out when we terminated observations.

Observers at the 'east' post counted 12 ringed seals hauled out on the ice at 14:00 within 2 km of the ship's projected track. Although we were unable to observe their immediate reaction to the ship, we did not observe any of them to dive within the few minutes after 17:14 when the ship entered the ice. Ten ringed seals were still hauled out at 18:00 and exhibited normal haul-out behaviour (i.e. intermittently attentive and resting). Individual ringed seals, swimming along the ice edge, were seen on four occasions by the observers during 15:00 to 18:00. All were thought to be pups of the year. Due to other observation priorities we did not follow their behaviour.

Many ringed seals remained hauled out on the fast ice along the ice edge throughout 29 June. One of the hunters remarked that several of the seals seemed reluctant to enter the water when he approached them with his snowmobile. Observers at the 'east' post found three bearded seals hauled out along ice cracks at the mouth of Elwin Inlet.

Post-Disturbance Period

The onset of the post-disturbance period cannot be clearly delineated. Whales had returned to the Admiralty Inlet ice edge by early morning on 30 June, although ship noise was still audible to human hearing on the hydrophones until about 15:00 on 30 June. At this time the ship was only audible during the back-down phase and transition phase of the ice-breaking cycle.

Received Noise Levels

Received levels of ship noise on 30 June are presented in the section of the results from the Disturbance Period. Several measurements of ambient noise levels (without ship noise) from the late afternoon on 30 June are presented below. Figure 28 gives the ambient spectra as recorded from our camp 500 m from the ice edge at 18:30. The ambient noise patterns are similar to those recorded from the same location on the morning of 28 June (Figs. 4, 5 and 6), although the noise levels tended to be a few dB lower on 30 June (Table A-24).

Figure 29 presents an example of the ambient noise recorded at the ice edge itself. The levels are substantially higher (Table A-25) than our other measurements of ambient noise. This is because a group of vocal narwhals was passing close to the hydrophone during this recording period. Note the substantially higher noise levels at most frequencies above 500 Hz. For example, the band level noise for the 1.6-3.2 kHz band was 97.5 dB//1 μPa at the ice edge (Table A-25), whereas it was only 86.8 dB at 500 m from the ice edge when the narwhals were not present nearby (Table A-24).

Figures 30 and 31 present the ambient spectra recorded at longer distances from the ice edge on 30 June; the hydrophone was 2.3 km from the ice edge (Fig. 30) and about 18 km from the edge (Fig. 31). Few animal sounds were heard at 18 km from the edge; only faint bearded seal calls were noted.

Whale Behaviour

At about 22:00 on 29 June the first belugas had reached the west end of the Admiralty Inlet ice edge arriving from the west (see previous section: Aerial Survey).

A narrow band of pack ice beset the ice edge early on 30 June but narwhals or belugas were heard (in air) about 05:00 as they moved eastward, beyond the pack ice, past the acoustic camp. At midday, the observers travelled east about 8 km by snowmobile and in an open embayment along the

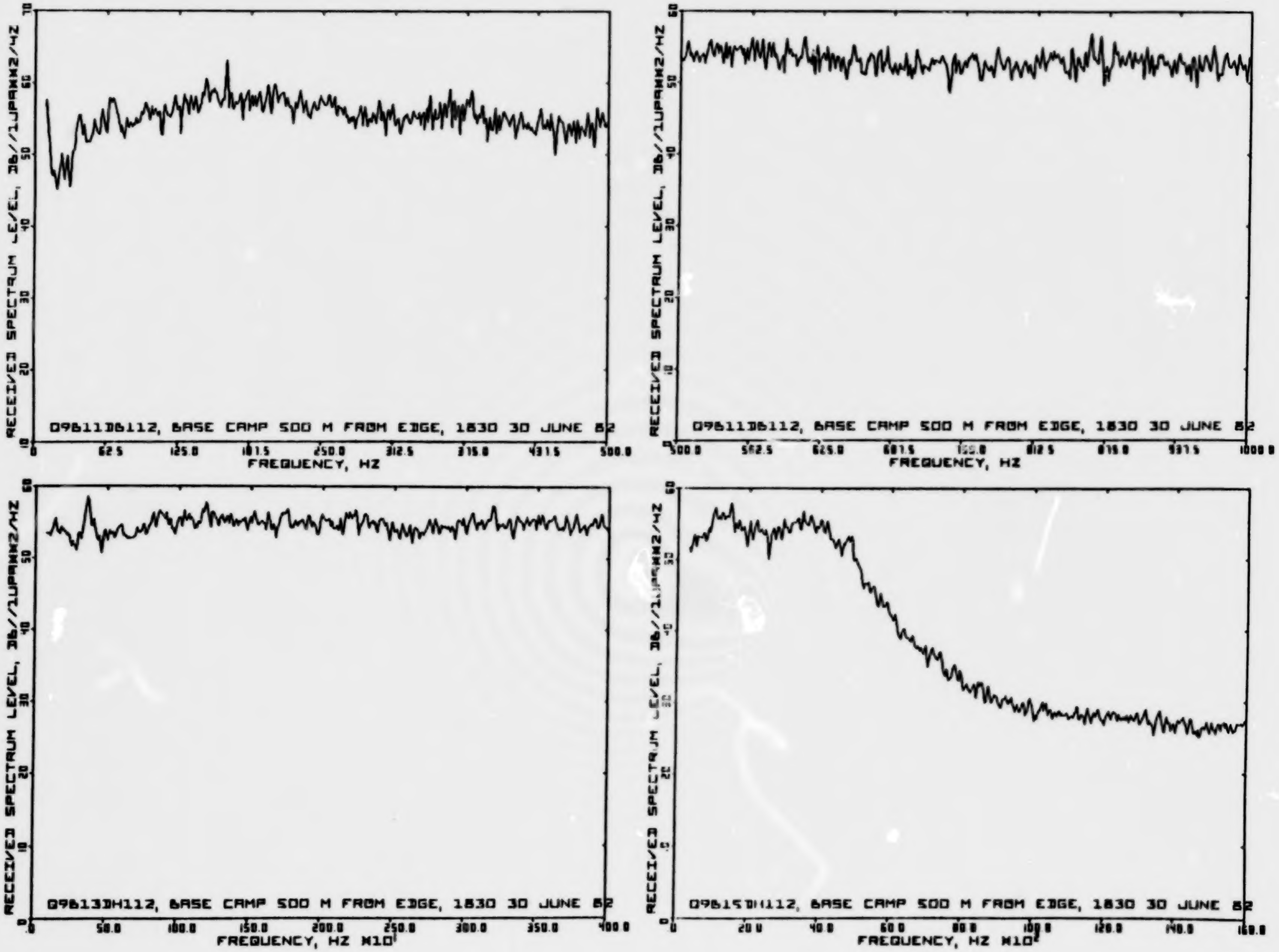

Fig. 28. Ambient noise spectra at 18:30, 30 June.

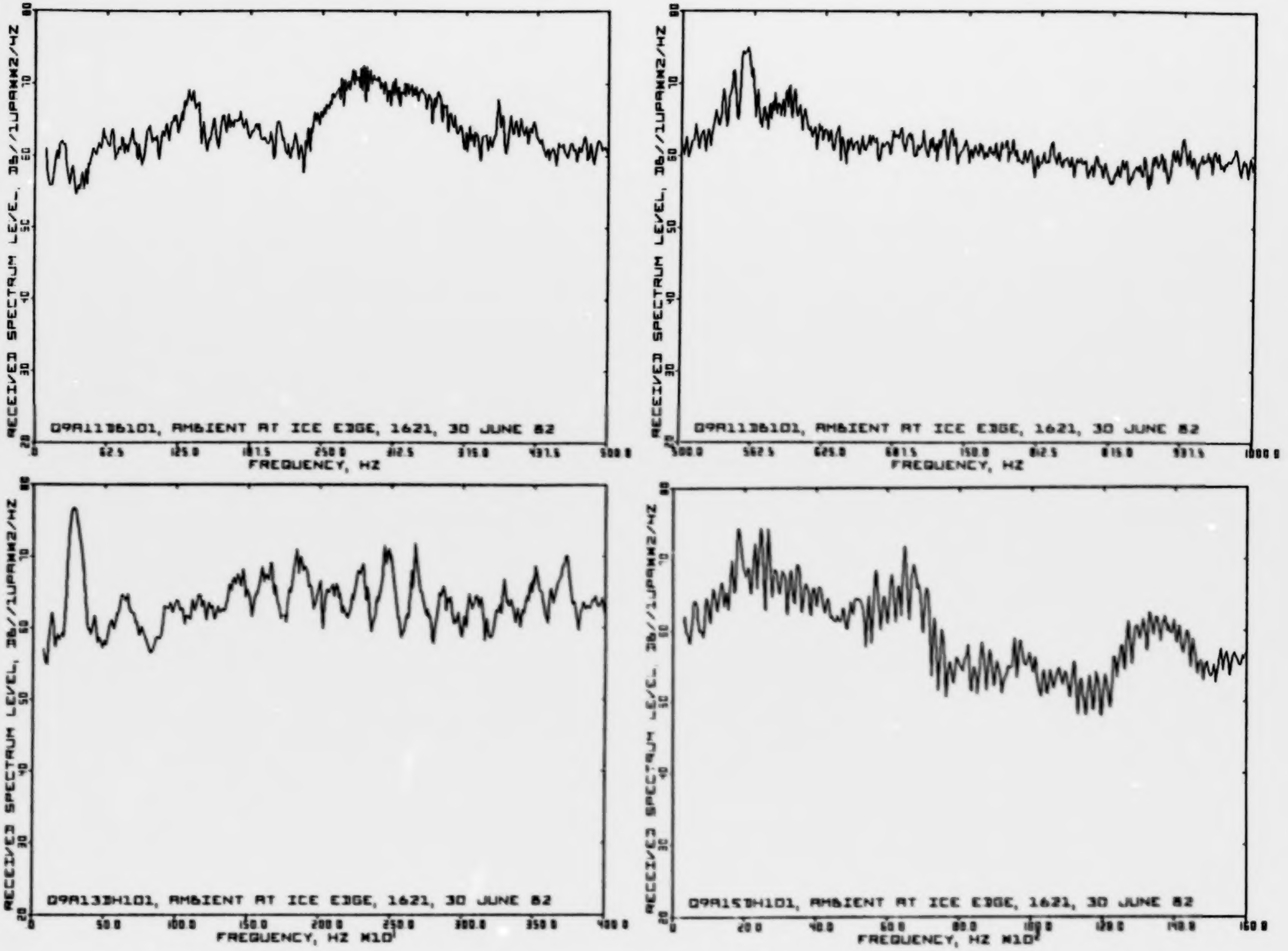

Fig. 29. Ambient noise spectra with narwhal sounds at the ice edge at 16:21, 30 June.

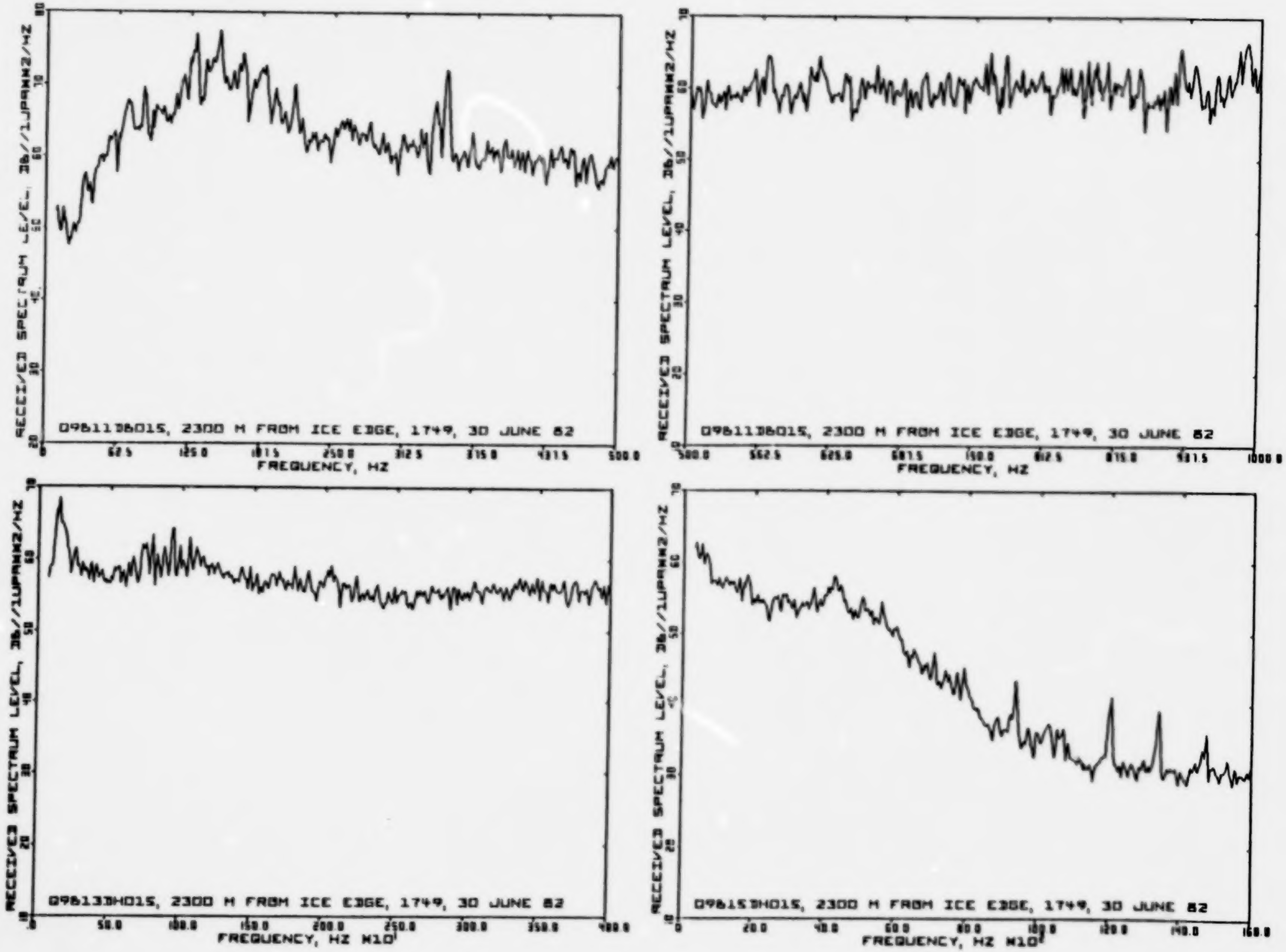

Fig. 30. Ambient noise spectra 2.3 km from the ice edge at 17:49, 30 June.

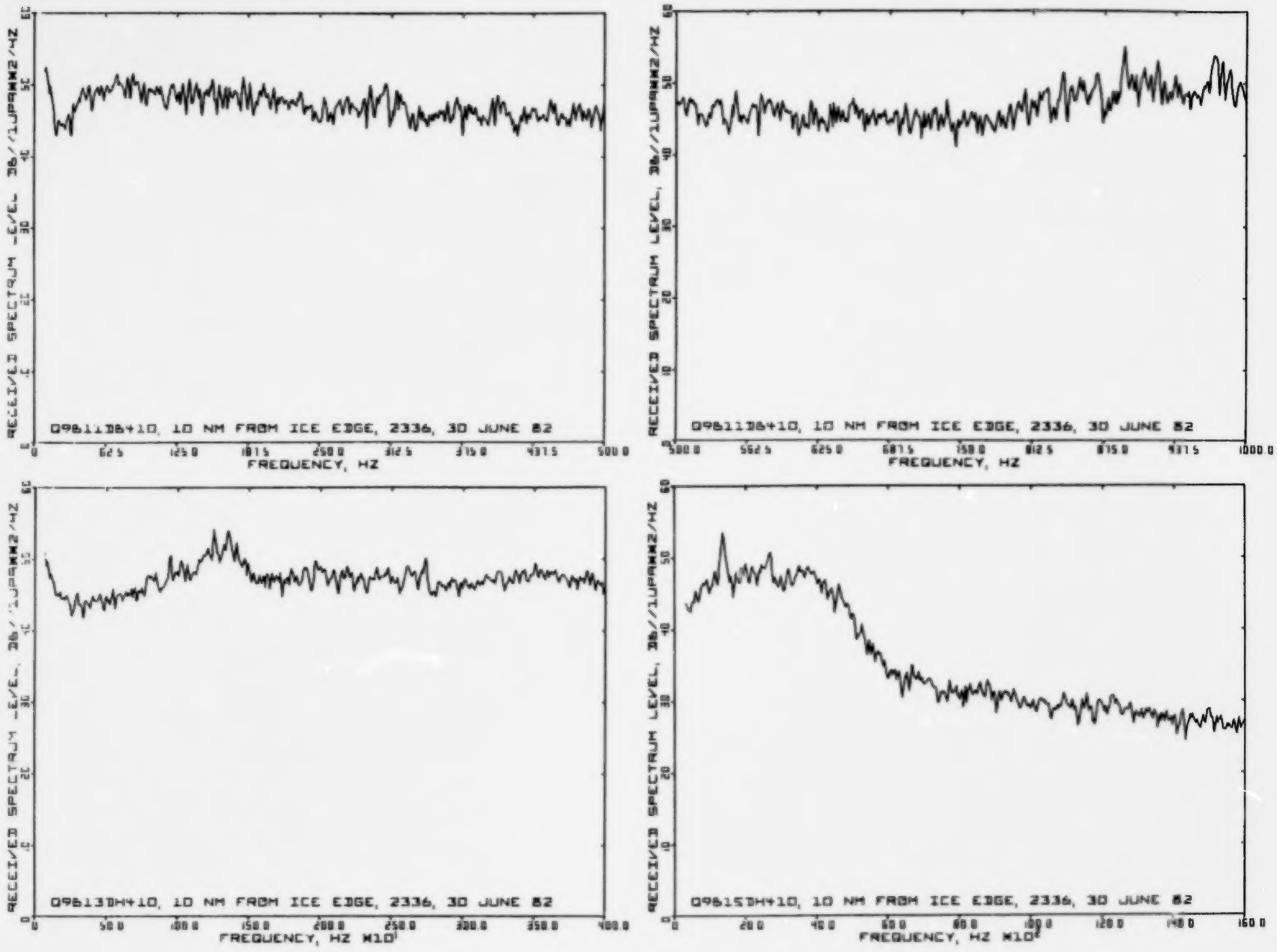

Fig. 31. Ambient noise spectra 18 km from the ice edge at 23:36, 30 June.

ice edge encountered a large mixed herd consisting of approximately 100 belugas and 100 narwhals engaged in a 'feeding frenzy' beneath the ice edge. This activity was concentrated within a 200-400 m stretch of the ice edge. Virtually all dives were oriented toward an indentation in the ice edge. The observers were able to approach quietly within 5 m of the activity without causing any perceptible change in the visible behaviour of the animals. A hydrophone was lowered 3 m through a narrow ice crack about 3 m from the ice edge and at the focus of the diving activity.

Dives were initiated within a few metres of the ice edge and the belugas and narwhals could be seen moving rapidly downward beneath the ice. The activity attracted small numbers of black-legged kittiwakes (*Rissa tridactyla*), long-tailed jaegers (*Stercorarius longicaudus*) and pomarine jaegers (*Stercorarius pomarinus*). On several occasions kittiwakes and long-tailed jaegers picked up small fish from among the feeding whales and on one occasion a pomarine jaeger forced a kittiwake to disgorge a fish on the ice near us. As suspected, it proved to be an arctic cod (*Boreogadus saida*).

Both belugas and narwhals dove in compact units in a highly organized manner. Often pods of the two species alternated, one after the other, in quick succession, although on two occasions the belugas appeared to withdraw a few hundred metres while the narwhals continued feeding. During such frenzied activity it was almost impossible to keep track of individuals and to estimate time spent beneath the ice edge. Many animals resurfaced among those diving while others resurfaced farther offshore, rested briefly, then turned and moved toward the indentation again. One recognizable beluga spent four min beneath the ice on one dive but it is not known whether this was representative of the others. A distinctively marked neonatal beluga was observed on several occasions resting at the surface near the ice edge, and on one occasion it dove briefly and surfaced in the company of an adult, presumably its mother. All sex and age groups of narwhals and belugas were represented among the feeding groups. Pods of male narwhals and male belugas remained distinct and more cohesive than did pods with females and young.

Diving activity slackened after about 1.5 h and the whales slowly dispersed from the area. The belugas generally moved westward and disappeared within the pack ice. The narwhals were the last to retreat and appeared to move offshore. When last observed at 15:00 several pods of narwhals were dispersed up to 1 km from the ice edge; many of the pods were immobile, apparently resting.

Around 15:30, CRG saw a small group of narwhals surface in the ship track about 200 m from the ice edge. These disappeared when the observer walked toward them. The track was ice free for a distance of 200 m from the ice edge.

Between 16:00 and 17:30 we obtained recordings of narwhals from the ice edge as several small groups (total of about 30-40 animals) of narwhals moved eastward in a narrow (100-300 m) lane between the ice edge and a belt of pack ice. The pack ice then closed in against the ice edge, effectively obscuring our view of open water.

The behaviour of belugas and narwhals observed on 30 June appeared typical of animals observed by one of us (KJF) in other undisturbed situations.

Whale Distribution

Admiralty Inlet

An aerial survey of the Admiralty Inlet ice edge and an adjacent coastal area toward Cape Joy was conducted between 20:30 and 20:56 on 30 June. We found 153 narwhals and 191 belugas in this area (Fig. 32). The narwhals were dispersed along the eastern portion of the ice edge and most groups were moving generally westward (Table 3). None remained in the vicinity where they had been observed feeding earlier in the day. Most of the belugas were observed along a shallow coastal shelf north of Elwin Inlet. Here most of the animals were engaged in bottom activity, presumably wallowing, creating mud boils and siltiness that obscured many individuals.

No whales were observed between the acoustic camp and Sargent Point, 66 km to the west. Thus, we presume that the belugas and narwhals seen on the eastern side of Admiralty Inlet were some or most of those that were observed feeding earlier in the day.

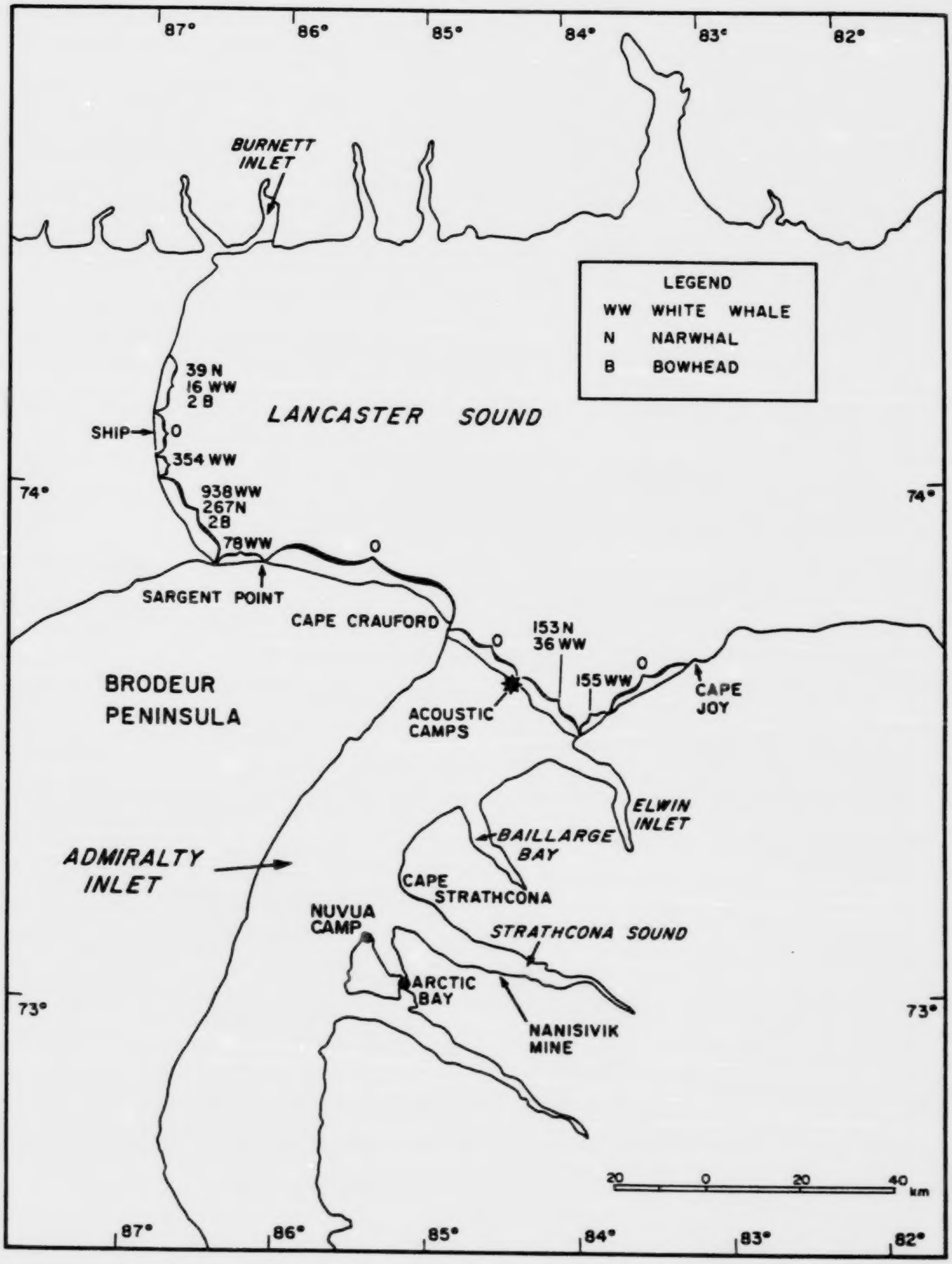
87°
86°
85°
84°
83°
82°
74°
73°
BURNETT INLET
LEGEND
WW WHITE WHALE
N NARWHAL
B BOWHEAD
LANCASTER SOUND
39 N
16 WW
2 B
SHIP
354 WW
938 WW
267 N
2 B
78 WW
SARGENT POINT
CAPE CRAUFORD
153 N
36 WW
155 WW
CAPE JOY
BRODEUR PENINSULA
ACOUSTIC CAMPS
ELWIN INLET
BAILLARGE BAY
ADMIRALTY INLET
CAPE STRATHCONA
NUVUA CAMP
STRATHCONA SOUND
ARCTIC BAY
NANISIVIK MINE
20
0
20
40
km

Fig. 32. Distribution and numbers of narwhals, white whales (belugas) and bowhead whales along the Admiralty Inlet ice edge, adjacent coastal areas and part of the Lancaster Sound ice edge between 20:30 and 22:07, 30 June. The position of the icebreaker John A. MacDonald is also shown.

Lancaster Sound and CCGS John A. MacDonald

Large numbers of belugas (1292, 27/lin km) and narwhals (267, 5.6/lin km) were found along the southern portion of the Lancaster Sound ice edge (Fig. 32). Many of the pods were resting and, initially, there was a perceptible northern movement, although slow, of many pods of belugas and narwhals (Table 3). Several pods of narwhals were undertaking dives directed beneath the ice edge.

At a point about 24 km along the ice edge, an abrupt change was noted in the orientation and movements of the belugas. At first, several pods were noted moving strongly toward the ice edge and then an almost continuous herd of over 350 animals was encountered in the next 5 km; all were moving rapidly south close to and beneath the ice edge. Undoubtedly we missed many animals that were beneath the ice. It became apparent that the change in behaviour of the belugas may have been related to the presence of the icebreaker, CCGS John A. MacDonald, that had nosed into the ice edge.

No whales were seen for about 3 km on either side of the icebreaker (Fig. 32), although the ship was at idle. It was noted that the first small groups of belugas north of the ship were moving generally south toward the ship but were deviating offshore from the ice edge. All groups of narwhals north of the ship were moving slowly south close to the ice edge. About 3 km north of the ship a pair of bowhead whales were immobile within a few metres of the ice edge.

Our observations of whales along the Lancaster Sound ice edge were made between 21:17 and 21:45. According to Captain Gallant (Can. Coast Guard, pers. comm.), the John A. MacDonald had reached the ice edge at 14:17. Although the icebreaker was motionless, onboard machinery would have been operating. However, we have no information concerning what machinery was operating and what the associated noise levels were. It is apparent that, although the presence of the ship did not stop whale movements along the ice edge, it did alter the behaviour of the animals as they moved past it.

Ship Track in Admiralty Inlet

After 22:00 on 30 June, we followed the ship track through Admiralty Inlet by helicopter to a point about 29 km from the ice edge. The ship track was filled with broken ice that appeared impenetrable to whales. We lowered a hydrophone into the ship track and monitored sounds for 2 min but heard no whale calls (see Fig. 31 for sound spectra from this station).

The MV Arctic reached the dock at Nanisivik mine around midnight on 30 June and shortly after began taking on its ore load. It departed, full, about midnight on 2 July.

On 4 July we accompanied Martin Luce of Canarctic Shipping Ltd. and members of the Arctic Bay Hunters and Trappers Association on a helicopter survey of the ship track. No whales were found in the track that was still jammed with rubble ice. Strong winds and fog prevented a full survey of the ice edge, but about 100 belugas and 200 narwhals were found amongst pan ice and ice cracks near Elwin Inlet.

1-7 July

Because strong winds and unstable ice we were unable to reach the Admiralty Inlet ice edge again until 5 July, well after the return passage of the ship. The ice bordering the open water was extensively cracked and an ice edge could not be easily detected when we arrived in foggy, windy conditions about midday on 5 July. Earlier in the day two hunters had encountered many narwhals swimming along an ice crack near Elwin Inlet. This encounter initiated the 'ice-crack' phase of the annual narwhal hunt and two large male narwhals were taken. This ended our study of undisturbed behaviour of narwhals.

Around noon on 7 July, the hunters observed that the fast ice had become unstable and they retreated to Nuvua camp where they prepared for the arrival of the narwhals through the ice cracks. They expected this to occur within a week.

Whale Vocalizations

The noise of the MV Arctic was still detectable at the ice edge during the morning of 30 June (ship 40-45 km away) but whale calls were numerous at 08:00 and 10:00. Many of the calls were indistinct pulsive sounds. 'Click series' were numerous (15+/s) and the average repetition rate of 6.6 ± 3.2/s (n = 9) was similar to that recorded on 27 June in the absence of disturbance. Tonal whistles, especially of the undulating and stepped-frequency types, comprised the largest proportion (50%) of the identifiable calls (n = 34); however, this is not thought to be representative of the repertoire at that time, since many indistinct calls were probably masked by the noise of the MV Arctic.

Recordings taken between 12:00 and 13:00 on 30 June in the presence of feeding narwhals and belugas (see previous section) were saturated with strong wide-band clicks and 'burst-pulse' sounds (Fig. 33). A constant 'clattering' or 'castanetting' sound covering the band between 3 and 5 kHz was the prevailing background against the strong echolocation signals. This 'clatter' was evident as a dense band of sound energy on recordings taken at the acoustic camp at 14:50 and at the ice edge at 17:15. The sound source is unknown but falls primarily in the 'click series' bandwidths (i.e. generally 3-5 kHz). 'Click series' were often distinctive against the 'clatter'.

Our last recording was taken at the ice edge at 17:15, as about 25-30 narwhals in several small pods passed the hydrophone moving slowly east. Click signals were the predominant sound produced and were of two types: those with regular repetition rates (4.7 ± 0.7/s; n = 4) between 2 and 6 kHz and those with changing repetition rates at low (0.1-1.0 kHz) frequencies. The latter click series were strong and shifted rapidly in amplitude, occasionally overloading our equipment. Only two other typical odontocete signals, a 3-part stepped whistle and a complex 'bray', were evident in a 1-min segment of spectrograph.

Source Levels of MV Arctic

The closest distance between the MV Arctic and our hydrophone was 463 m (0.25 n.mi.). The water depth in the area was about 340 m as indicated by Canada Hydrographic Service charts. Some of the sound spectra recorded in this situation indicated interference between bottom-reflected sound energy and direct-arriving energy. Nevertheless, as a first approximation we may neglect the effect of bottom-arriving energy and assume spherical spreading to compute the source level of the ship noise referred to an effective distance of 1 m. The correction for spherical spreading at a range of 463 m is 53.3 dB.

The estimated source levels for the MV Arctic operating in ice are presented in Table 5. This band level analysis indicates that the ship made substantially more noise when going astern in ice than it did when going ahead. The levels in Table 5 for the going-ahead mode are averages based on eight samples from the low-frequency hydrophone and seven from the wideband hydrophone. The going-astern levels are the averages of five samples.

The source levels have been converted into spectrum levels and are presented in Figure 34 for the going-ahead mode and Figure 35 for going astern. When comparing these figures, it is important to note that their scales are different. Again, the source levels are generally higher when the ship is going astern. The 'dip' in the spectrum between 28 and 45 Hz in the going-ahead mode is caused by multipath interference at the receiving distance. It has not been artificially removed in Figure 34.

A striking feature of the 'going-ahead' in ice spectrum is the strong tone of 205 Hz. The source level of this tone is calculated to have been 171.4 dB//1 μPa-m. We do not know what machinery on the ship generated this tone, but subsequent study in 1983 suggests that the source was the 'bubbler system' on the Arctic (see Finley et al. 1984). However, it is interesting to note that the tone was not present when the ship was going astern. It was this tone that was first detectable in the acoustic analyses (at a range of 105 km) when the ship was approaching Admiralty Inlet. There was also a very strong tone present at 53 Hz; the estimated source level was 171.5 dB//1

Fig. 33. Spectrographic representation (2 cm/s) of marine mammal sounds and the noise of the MV Arctic, 27-30 June, 1982.

(A) 27 June. Whistles and yelps of whales predominate between 1-6 kHz while continuous bearded seal calls constitute the lower band.

(B) 28 June. High pitched screams and numerous click series of whales prodominate in a wide-band (2-8 kHz) while the noise of the MV Arctic, at 45 km, predominates below 2 kHz.

(C) 29 June. The noise of the MV Arctic predominates below 6 kHz.

(D) 30 June. Recording taken in the presence of feeding belugas and narwhals. Strong broad-band clicks and burst pulses predominate at frequencies below about 2 kHz. Harmonic components and whistles extend up to 10 kHz. The apparent hiatus of sound between 3-6 kHz is an artefact produced by volume-level changes for the two bandwidths that are combined here.

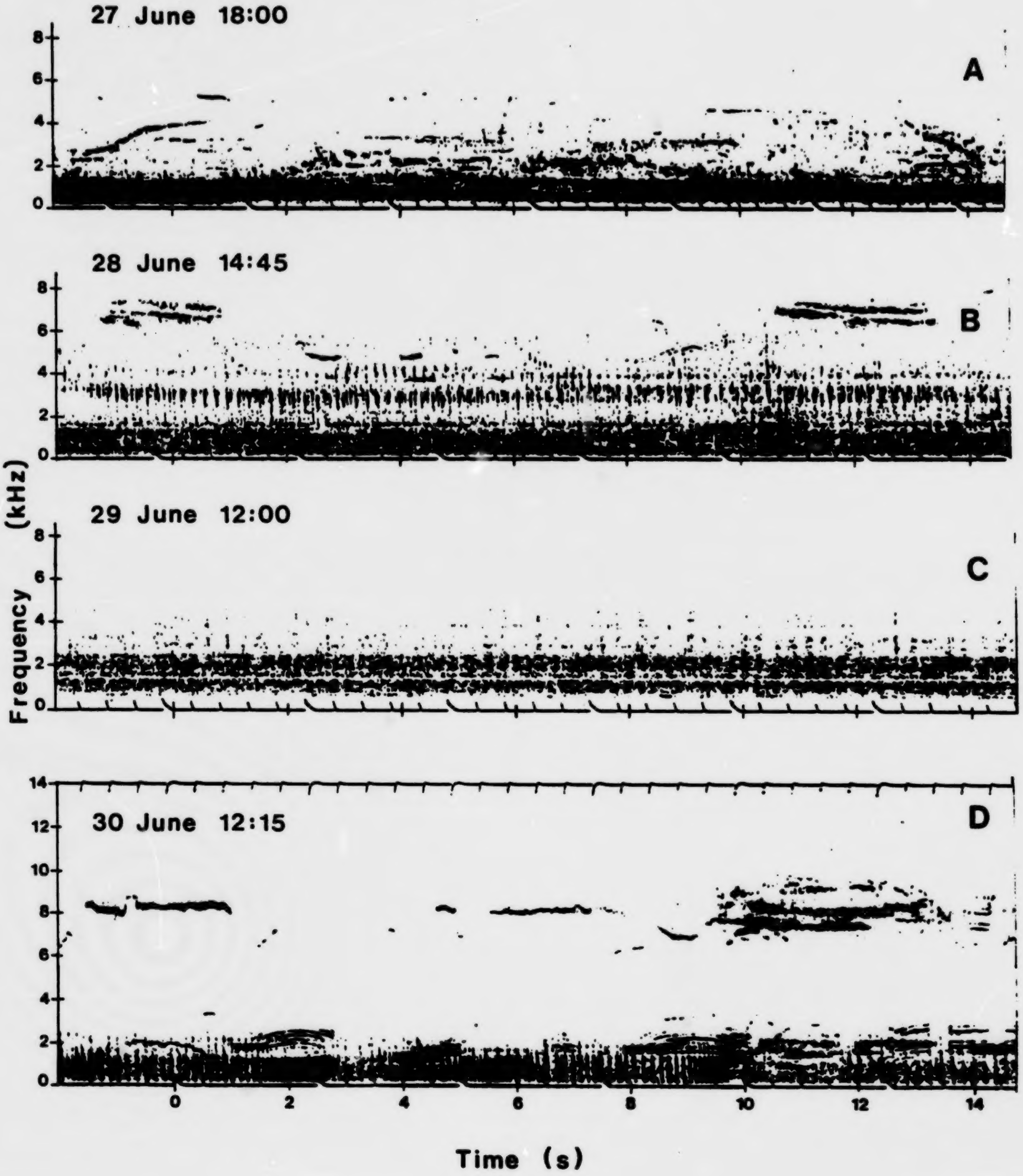
27 June 18:00
A
28 June 14:45
B
29 June 12:00
C
30 June 12:15
D
Frequency (kHz)
0
2
4
6
8
10
12
14
Time (s)

Table 5. Estimated source levels for MV Arctic operating in ice.

Frequency band (Hz)	dB//1 μPa-m	
	Going ahead	Going astern
10-500	183	190
100-500	179	185
200-500	177	180
10-1000	184	191
100-1000	181	186
200-1000	180	182
10-20	168	177
20-40	172	181
40-80	179	184
80-160	176	187
160-320	176	179
320-640	176	179
100-200	176	183
200-400	176	178
400-800	177	179
80-4000	181	185
800-4000	178	179
1600-4000	174	176
800-1600	176	176
1600-3200	173	175
320-16000	180	182
3200-16000	171	176
6400-16000	163	170
3200-6400	170	174
6400-12800	163	169

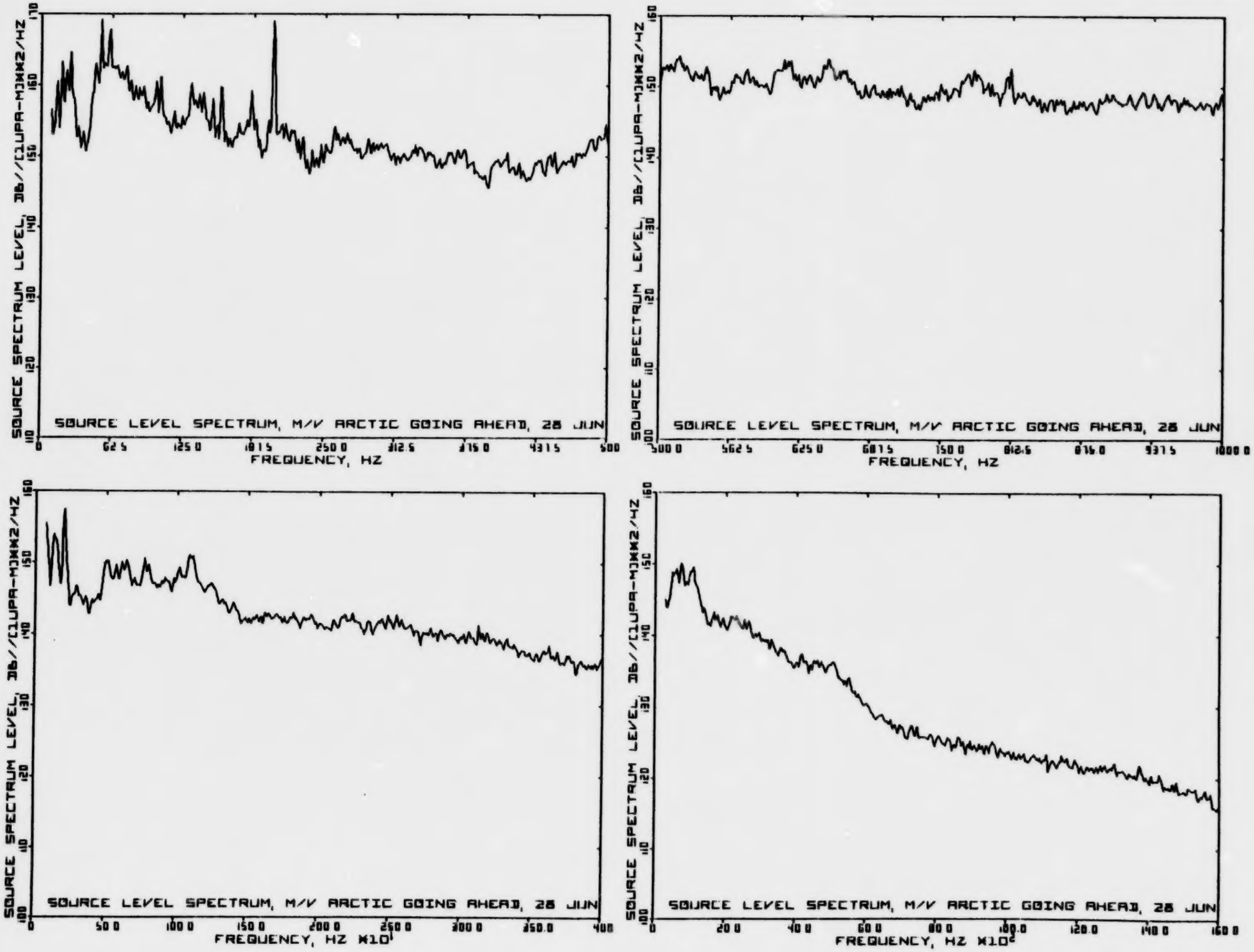

Fig. 34. Source level spectrum of the MV Arctic going ahead.

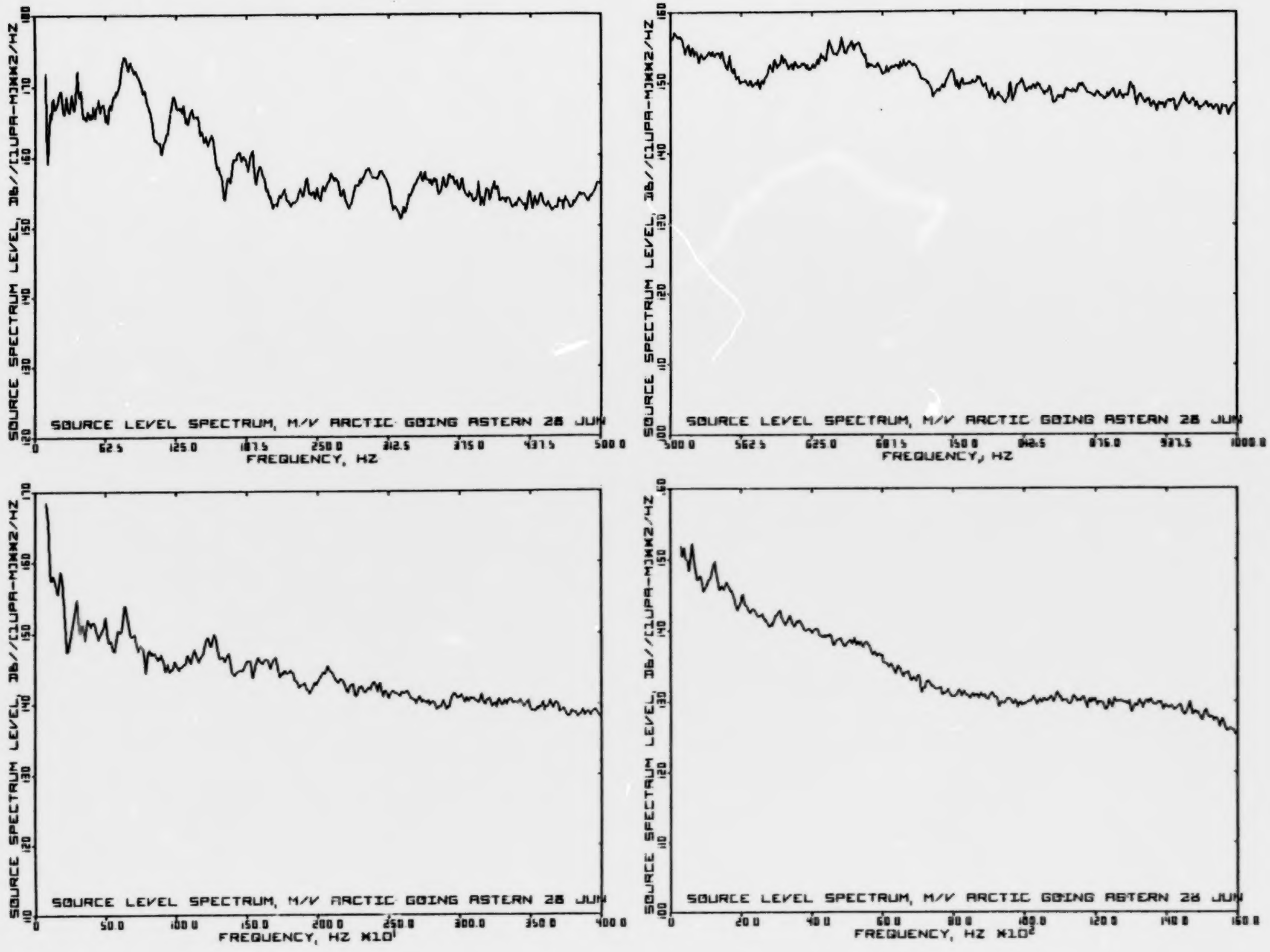

Fig. 35. Source level spectrum of the MV Arctic going astern.

μPa-m. This tone corresponds to the cylinder firing rate of the diesel engine on the MV Arctic. Again, this tone was not evident when the ship was going astern. It probably was present but not evident because of the increased cavitation noise when in reverse.

The tonal analysis (not presented) indicated that the strongest tones when the ship was going astern occurred at 14 Hz (168.6 dB//1 μPa-m), 38 Hz (174.5 dB), 79 Hz (176.5 dB), and 123 Hz (171 dB).

DISCUSSION AND SUMMARY

There have been no quantitative studies of the potential effects of shipping on marine mammals in the eastern North American arctic. The study reported here is the first such attempt. Studies of the effects of offshore industrial activities (including ships) on bowheads and belugas have been conducted in the Beaufort Sea for several years (Ford 1977; Fraker 1977; Fraker and Fraker 1982; Richardson et al. 1982). Briefly, the results of the beluga studies in the Beaufort Sea have shown that, although whales can show marked reactions to closely approaching ships, no longer-term changes in use of the Mackenzie estuary have been noted. The southeastern Beaufort Sea has been subject to increasing levels of offshore activity since the early 1970's. Levels of activity in 1982 in the Beaufort Sea (Richardson et al. 1983) were quite high. It is reasonable to assume that belugas in this area have had several years to habituate to this industrial activity.

The situation in Admiralty Inlet is substantially different. Whales in this area have been subject to only very low levels of shipping--a few passages in the open water season. Even these few passages have led the residents of Arctic Bay to conclude that narwhals may be changing their distribution patterns in response. The Inuit are also concerned that increased harrassment associated with their hunting of narwhals may be affecting narwhal distribution. The reactions of belugas and narwhals to the approaching ship in Admiralty Inlet were much more marked than reactions of belugas in the Beaufort Sea. This suggests that populations in the eastern arctic may be relatively 'naive' with respect to shipping.

Reactions to the MV Arctic

Our study was hampered by our inability to obtain a time-series of normal undisturbed whale behaviour over a 3 to 5 day period before the ship arrived. We have only about one day of observations, although one of us (KJF) has observed narwhals and belugas in this general area for several years. The behaviour of both species was considered normal on 27 June and on the morning of 28 June, although relatively small numbers of each species were present along the ice edge across Admiralty Inlet.

The MV Arctic approached the ice edge from the northeast and north on 28 June. Ship noise was first detectable in our acoustic analyses when the ship was 105 km distant at 12:15 on 28 June. A 205 Hz tone was present on the noise spectra at this time. Later measurements indicated that this tone had source levels of up to 171.4 dB//1 μPa-m. The received level of the tone at 12:15 was about 64 dB//1 μPa indicating that propagation loss north of the ice edge was dominated by spherical spreading. It should be noted that the tone was not audible above the background noise to human listeners on the hydrophones at 12:15.

A very rapid westward movement of belugas along the ice edge began at 15:00 and continued for over an hour. At this time the MV Arctic was 39 km from the ice edge and approaching it from the north. The rapid beluga movement involved very high speeds (>20 km/h) that have not previously been recorded. Both KJF and the Inuit members of the observation team noted that the swimming behaviour was atypical and lacked synchrony. The vocal behaviour of the belugas also changed during this rapid movement along the ice edge. It was only during this period that complex 'screams' and pulsive sounds (e.g., buzzes) dominated their repertoire.

As the ship approached closer (about 15 km) to the ice edge at 16:30, the behaviour of the belugas changed again. Movements became confused with frequent directional changes and milling about. Many dove under the ice. When the ship was less than 2 km from the ice, most of the belugas east of the ship moved off slowly to the east, whereas those west of the ship continued to move rapidly westward.

The behaviour of narwhals as the ship approached was much different than that of the belugas. The animals remained quiet and often remained motionless close to the ice edge. Unlike the rapid mass movement shown by belugas, narwhal movements appeared in independent tightly cohesive pods. Instead of diving they tended to 'sink' submerge. All of the narwhals had moved offshore away from the ice edge within an hour of the ship's arrival at the edge.

The Inuit members of the observation team recognized the behaviour of the belugas and narwhals as 'ardlingayuk'--meaning literally 'fear of killer whales'. The Inuit say that, typically, when threatened the whales respond by seeking shelter in the ice, as we observed, or in shallow water when ice is not available. The notable differences in behaviour between the two species (i.e. fleeing by belugas and 'freezing' by narwhals) were thought by the Inuit to be the typical reactions of each species in the presence of killer whales. The Inuit hunters also note that another feature of 'ardlingayuk' behaviour is that the whales cease producing sounds, at least those audible in air.

The available evidence indicates that both species were reacting to the approaching ship. Surprisingly, the belugas began to react when the ship was still 35-40 km away, but approaching fast (27 km/h). Unfortunately, we do not have recordings of received ship noise levels when the belugas began to react at 15:00. Received noise levels from before and during this period of reaction are presented in the Results (Figs. 11 and 12 et seq.). The ship was clearly audible on the hydrophones by 14:31, although animal sounds continued to dominate the spectra. At 16:11, when the ship was 20 km from the ice edge, noise levels were elevated substantially above ambient levels--e.g., 12 dB//1 µPa in the 400-800 Hz band, 18 dB in the 1.6-3.2 kHz band, and 17 dB in the 2.56-5.12 kHz band. Even when the ship was closer (6.4 km), animals sounds were still clearly evident on the spectra but only at the higher frequencies that were not dominated by ship noise. Animal sounds were no longer detectable, even with low frequencies filtered out, at 17:03 when the ship was about 3.5 km away.

Belugas and narwhals left the Admiralty Inlet ice edge soon after the ship arrived. Large numbers of belugas were found along the north coast of the Brodeur Peninsula to the west of the ice edge on 29 June. Most of the belugas that left the edge when the ship arrived moved toward this area. By late on 29 June, belugas were moving east along the Brodeur Peninsula coast toward the ice edge. The first animals reached the ice edge by about 23:00--about 30 h after the ship had arrived. Belugas and narwhals were present along the ice edge by midday on 30 June. Behaviour was apparently normal. Their vocal behaviour was also more similar to the repertoire used in the pre-disturbance period.

It is not certain that the animals that returned on 30 June were the same individuals that were present on 28 June when the ship arrived. However, the directions of the departing and arriving belugas suggest that at least some of the same individuals could have been involved. Thus, we conclude that belugas and narwhals markedly reacted to the MV Arctic and left the Admiralty Inlet ice edge. Both species returned to the edge, in similar numbers, within 30 to 40 h after the arrival of the ship. It is likely that at least some of the returning belugas were the same individuals that left the area when the ship arrived.

Whale Vocalizations

The information available in 1982 on sounds produced by narwhals and belugas was not sufficient to allow us to clearly attribute our data to one species or the other or draw any firm conclusions about their behavioural context. In general, it is reasonable to assume that the majority of the tonal signals can be attributed to the beluga, which has a well-deserved reputation as the 'sea canary'. The sweep-frequency sounds also appear to originate from the beluga (Fish and Mowbray 1962). Narwhals appear to emit primarily pulsive sounds but also some tonal sounds (Watkins et al. 1971; Ford and Fisher 1978).

'Clicks' are generally associated with echolocation for feeding and orientation in most odontocetes but they are also thought to be used by some species, such as the narwhal and sperm whale (Physeter catodon), as identification coda and to maintain social or spatial order (Watkins and Schevill 1977a,b; Watkins 1980a,b). The narrow-band click series heard throughout much of our recording period can be attributed to narwhals. Watkins et al. (1971) suggested that these sounds are used primarily as communication signals, and Ford and Fisher (1978) speculated that they are used in echolocation. The absence of the 'click series' after 16:00 as the MV Arctic was close to the ice edge suggests that the narwhals that were present ceased this form of vocalization.

The origin of the complex 'screams' and pulsive sounds that were so notable on the afternoon of 28 June are not known with certainty but it seems likely that many or most of the calls came from the belugas that were moving rapidly west by the acoustic camp in advance of the ship's arrival. Such calls may have an alarm function but in the absence of more data from undisturbed situations, this remains speculative. Future work in the exclusive presence of one of these species should help to establish the contextual and functional aspects of these and other calls under various circumstances.

Ambient Noise

A fairly large sample of ambient noise measurements were made during this study. Only a representative sample has been analyzed and presented in this report. It is not the objective of this report to make detailed comparisons with results from other workers in other areas. Our results are typical of expected ambient levels that are dominated by biological noise sources.

Ship Noise

Detailed information on the received levels of ship noise at various distances and in various conditions are presented in the report. In addition, estimated source levels are calculated for the icebreaking mode, both going-forward and going-astern. The loudest noises occur during the brief (5 s) transition from reverse to forward thrust during the icebreaking mode. The going-astern noises are substantially louder (about 5 dB) than noises associated with the forward mode through ice.

It is outside the term of reference of this study to make a detailed review of the literature on ship noise levels. However, an interesting finding of this study is that some of the loudest noises produced by the MV Arctic are machinery noises that are not related to propeller cavitation noise. These noises are tones and some occur at frequencies that are higher than the principal cavitation noise. These higher frequency noises are closer to the hearing and communication frequency ranges used by marine mammals than are cavitation noise and blade-rate tonals.

The most prominant tones (source levels of 171 dB//1 μPa-m) when the ship is moving forward occur at 53 Hz and 205 Hz. The former is associated with the cylinder firing rate of the diesel engine on the ship and the latter with the 'bubbler system' on the ship. Tones at different frequencies (14, 38, 79 and 123 Hz) dominate the spectra when the ship is going astern. Source levels for these tones range from 168 to 176.5 dB//1 μPa-m.

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APPENDIX A—BAND LEVEL ANALYSES

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Table A1. Band level analyses at 13:14, 27 June, 1982.

```
Q1A11DB365. AMBIENT SOUNDS AT FIRST CAMP. 1314. 27 JUN

FREQUENCY RANGE       BAND LEVEL
  FROM      TO      DB RE
     (HZ)           1UPA   UPA**2

    10.0   500.0    82.8  1.892E  8
   100.0   500.0    82.3  1.689E  8
   200.0   500.0    80.7  1.176E  8
    10.0  1000.0    85.1  3.225E  8
   100.0  1000.0    84.8  3.021E  8
   200.0  1000.0    84.0  2.508E  8
    10.0    20.0    57.8  6.004E  5
    20.0    40.0    63.0  1.985E  6
    40.0    80.0    70.5  1.126E  7
    80.0   160.0    75.6  3.614E  7
   160.0   320.0    79.7  9.416E  7
   320.0   640.0    78.7  7.330E  7
   100.0   200.0    77.1  5.128E  7
   200.0   400.0    79.9  9.754E  7
   400.0   800.0    80.9  1.224E  8
Q1A13DH365. AMBIENT SOUNDS AT FIRST CAMP. 1314. 27 JUN

FREQUENCY RANGE       BAND LEVEL
  FROM      TO      DB RE
     (HZ)           1UPA   UPA**2

    80.0  4000.0    91.8  1.503E  9
   800.0  4000.0    89.6  9.201E  8
  1600.0  4000.0    85.6  3.624E  8
    80.0   160.0    79.4  8.639E  7
   160.0   320.0    82.2  1.657E  8
   320.0   640.0    82.8  1.903E  8
   640.0  1280.0    87.3  5.331E  8
  1280.0  2560.0    85.9  3.851E  8
   800.0  1600.0    87.5  5.577E  8
  1600.0  3200.0    84.7  2.940E  8

Q1A.5DH365. AMBIENT SOUNDS AT FIRST CAMP. 1314. 27 JUN

FREQUENCY RANGE       BAND LEVEL
  FROM      TO      DB RE
     (HZ)           1UPA   UPA**2

   320.0 16000.0    90.9  1.237E  9
  3200.0 16000.0    81.4  1.367E  8
  6400.0 16000.0    68.8  7.545E  6
   320.0   640.0    83.1  2.019E  8
   640.0  1280.0    87.1  5.154E  8
  1280.0  2560.0    84.8  3.048E  8
  2560.0  5120.0    83.0  1.973E  8
  5120.0 10240.0    71.6  1.442E  7
  3200.0  6400.0    81.1  1.291E  8
  6400.0 12800.0    67.8  6.016E  6
```

Table A2. Band level analyses at 00:36, 28 June, 1982.

```
Q2A11DB037. AMBIENT SOUNDS AT 2ND CAMP. 0036. 28 JUNE

FREQUENCY RANGE       BAND LEVEL
  FROM      TO      DB RE
     (HZ)           1UPA   UPA**2

    10.0   500.0    83.6  2.311E  8
   100.0   500.0    82.7  1.882E  8
   200.0   500.0    81.2  1.323E  8
    10.0  1000.0    85.2  3.319E  8
   100.0  1000.0    84.6  2.890E  8
   200.0  1000.0    83.7  2.331E  8
    10.0    20.0    63.9  2.464E  6
    20.0    40.0    69.8  9.465E  6
    40.0    80.0    72.9  1.931E  7
    80.0   160.0    76.4  4.341E  7
   160.0   320.0    79.3  8.576E  7
   320.0   640.0    80.2  1.057E  8
   100.0   200.0    77.5  5.594E  7
   200.0   400.0    80.2  1.040E  8
   400.0   800.0    79.8  9.460E  7
Q2A13DH037. AMBIENT SOUNDS AT 2ND CAMP. 0036. 28 JUNE

FREQUENCY RANGE       BAND LEVEL
  FROM      TO      DB RE
     (HZ)           1UPA   UPA**2

    80.0  4000.0    92.8  1.899E  9
   800.0  4000.0    91.1  1.279E  9
  1600.0  4000.0    89.1  8.129E  8
    80.0   160.0    80.4  1.092E  8
   160.0   320.0    82.0  1.579E  8
   320.0   640.0    84.1  2.590E  8
   640.0  1280.0    85.9  3.908E  8
  1280.0  2560.0    88.9  7.739E  8
   800.0  1600.0    86.7  4.659E  8
  1600.0  3200.0    88.6  7.176E  8

Q2A15DH037. AMBIENT SOUNDS AT 2ND CAMP. 0036. 28 JUNE

FREQUENCY RANGE       BAND LEVEL
  FROM      TO      DB RE
     (HZ)           1UPA   UPA**2

   320.0 16000.0    93.6  2.266E  9
  3200.0 16000.0    84.3  2.719E  8
  6400.0 16000.0    72.9  1.967E  7
   320.0   640.0    84.8  3.019E  8
   640.0  1280.0    86.6  4.616E  8
  1280.0  2560.0    90.5  1.111E  9
  2560.0  5120.0    85.0  3.153E  8
  5120.0 10240.0    78.4  6.958E  7
  3200.0  6400.0    84.0  2.523E  8
  6400.0 12800.0    72.2  1.657E  7
```

Table A3. Band level analyses at 06:20, 28 June, 1982.

```
Q2A11DH097. 6:20 AM. 6-28-82. 20 M H56. M/V ARCTIC

   10.0 TO  500.0 HZ. NOISE POWER IS  89.156 DB//1UPA OR 8.233E  8 UPA**2.
  100.0 TO  500.0 HZ. NOISE POWER IS  88.165 DB//1UPA OR 6.555E  8 UPA**2.
   10.0 TO 1000.0 HZ. NOISE POWER IS  90.887 DB//1UPA OR 1.227E  9 UPA**2.
  100.0 TO 1000.0 HZ. NOISE POWER IS  90.248 DB//1UPA OR 1.059E  9 UPA**2.
  200.0 TO 1000.0 HZ. NOISE POWER IS  89.259 DB//1UPA OR 8.431E  8 UPA**2.
   10.0 TO   20.0 HZ. NOISE POWER IS  71.647 DB//1UPA OR 1.461E  7 UPA**2.
   20.0 TO   40.0 HZ. NOISE POWER IS  71.478 DB//1UPA OR 1.405E  7 UPA**2.
   40.0 TO   80.0 HZ. NOISE POWER IS  79.106 DB//1UPA OR 8.140E  7 UPA**2.
   80.0 TO  160.0 HZ. NOISE POWER IS  82.829 DB//1UPA OR 1.918E  8 UPA**2.
  160.0 TO  320.0 HZ. NOISE POWER IS  84.633 DB//1UPA OR 2.906E  8 UPA**2.
  320.0 TO  640.0 HZ. NOISE POWER IS  86.134 DB//1UPA OR 4.106E  8 UPA**2.
  100.0 TO  200.0 HZ. NOISE POWER IS  83.338 DB//1UPA OR 2.157E  8 UPA**2.
  200.0 TO  400.0 HZ. NOISE POWER IS  84.765 DB//1UPA OR 2.995E  8 UPA**2.
  400.0 TO  800.0 HZ. NOISE POWER IS  86.375 DB//1UPA OR 4.340E  8 UPA**2.
```

```
Q2A13DH097. M/V ARCTIC. 0620. 6-28-82. 20 M H56 HYD

   80.0 TO 4000.0 HZ. NOISE POWER IS  92.720 DB//1UPA OR 1.871E  9 UPA**2.
  800.0 TO 4000.0 HZ. NOISE POWER IS  89.332 DB//1UPA OR 8.574E  8 UPA**2.
 1600.0 TO 4000.0 HZ. NOISE POWER IS  86.513 DB//1UPA OR 4.480E  8 UPA**2.
   80.0 TO  160.0 HZ. NOISE POWER IS  83.364 DB//1UPA OR 2.170E  8 UPA**2.
  160.0 TO  320.0 HZ. NOISE POWER IS  84.343 DB//1UPA OR 2.718E  8 UPA**2.
  320.0 TO  640.0 HZ. NOISE POWER IS  85.944 DB//1UPA OR 3.930E  8 UPA**2.
  640.0 TO 1280.0 HZ. NOISE POWER IS  86.155 DB//1UPA OR 4.126E  8 UPA**2.
 1280.0 TO 2560.0 HZ. NOISE POWER IS  85.248 DB//1UPA OR 3.348E  8 UPA**2.
  800.0 TO 1600.0 HZ. NOISE POWER IS  86.121 DB//1UPA OR 4.093E  8 UPA**2.
 1600.0 TO 3200.0 HZ. NOISE POWER IS  84.684 DB//1UPA OR 2.941E  8 UPA**2.
```

```
Q2A15DH097. M/V ARCTIC. 0620. 6-28-82. 20 M H56 HYD

  320.0 TO16000.0 HZ. NOISE POWER IS  92.472 DB//1UPA OR 1.767E  9 UPA**2.
 3200.0 TO16000.0 HZ. NOISE POWER IS  87.714 DB//1UPA OR 5.908E  8 UPA**2.
 6400.0 TO16000.0 HZ. NOISE POWER IS  76.450 DB//1UPA OR 4.416E  7 UPA**2.
  320.0 TO  640.0 HZ. NOISE POWER IS  85.448 DB//1UPA OR 3.506E  8 UPA**2.
  640.0 TO 1280.0 HZ. NOISE POWER IS  85.911 DB//1UPA OR 3.900E  8 UPA**2.
 1280.0 TO 2560.0 HZ. NOISE POWER IS  85.234 DB//1UPA OR 3.337E  8 UPA**2.
 2560.0 TO 5120.0 HZ. NOISE POWER IS  86.768 DB//1UPA OR 4.751E  8 UPA**2.
 5120.0 TO10240.0 HZ. NOISE POWER IS  83.210 DB//1UPA OR 2.094E  8 UPA**2.
 3200.0 TO 6400.0 HZ. NOISE POWER IS  87.377 DB//1UPA OR 5.467E  8 UPA**2.
 6400.0 TO12800.0 HZ. NOISE POWER IS  76.029 DB//1UPA OR 4.007E  7 UPA**2.
```

Table A4. Band level analyses at 09:15, 28 June. 1982.

```
Q2A11DH343. M/V ARCTIC. 0915 6-28-82. 20 M H56

   10.0 TO  500.0 HZ. NOISE POWER IS  84.846 DB//1UPA OR 3.052E  8 UPA**2.
  100.0 TO  500.0 HZ. NOISE POWER IS  83.999 DB//1UPA OR 2.511E  8 UPA**2.
  200.0 TO  500.0 HZ. NOISE POWER IS  82.458 DB//1UPA OR 1.761E  8 UPA**2.
   10.0 TO 1000.0 HZ. NOISE POWER IS  87.564 DB//1UPA OR 5.707E  8 UPA**2.
  100.0 TO 1000.0 HZ. NOISE POWER IS  87.132 DB//1UPA OR 5.166E  8 UPA**2.
  200.0 TO 1000.0 HZ. NOISE POWER IS  86.451 DB//1UPA OR 4.416E  8 UPA**2.
   10.0 TO   20.0 HZ. NOISE POWER IS  72.667 DB//1UPA OR 1.848E  7 UPA**2.
   20.0 TO   40.0 HZ. NOISE POWER IS  69.130 DB//1UPA OR 8.184E  6 UPA**2.
   40.0 TO   80.0 HZ. NOISE POWER IS  71.887 DB//1UPA OR 1.544E  7 UPA**2.
   80.0 TO  160.0 HZ. NOISE POWER IS  77.551 DB//1UPA OR 5.690E  7 UPA**2.
  160.0 TO  320.0 HZ. NOISE POWER IS  80.531 DB//1UPA OR 1.130E  8 UPA**2.
  320.0 TO  640.0 HZ. NOISE POWER IS  82.013 DB//1UPA OR 1.590E  8 UPA**2.
  100.0 TO  200.0 HZ. NOISE POWER IS  78.750 DB//1UPA OR 7.499E  7 UPA**2.
  200.0 TO  400.0 HZ. NOISE POWER IS  80.985 DB//1UPA OR 1.254E  8 UPA**2.
  400.0 TO  800.0 HZ. NOISE POWER IS  83.630 DB//1UPA OR 2.307E  8 UPA**2.
```

```
Q2A13DH343. M/V ARCTIC. 0915 6-28-82. 20 M H56

   80.0 TO 4000.0 HZ. NOISE POWER IS  90.692 DB//1UPA OR 1.173E  9 UPA**2.
  800.0 TO 4000.0 HZ. NOISE POWER IS  88.690 DB//1UPA OR 7.397E  8 UPA**2.
 1600.0 TO 4000.0 HZ. NOISE POWER IS  86.212 DB//1UPA OR 4.180E  8 UPA**2.
   80.0 TO  160.0 HZ. NOISE POWER IS  77.692 DB//1UPA OR 5.877E  7 UPA**2.
  160.0 TO  320.0 HZ. NOISE POWER IS  80.888 DB//1UPA OR 1.227E  8 UPA**2.
  320.0 TO  640.0 HZ. NOISE POWER IS  81.867 DB//1UPA OR 1.537E  8 UPA**2.
  640.0 TO 1280.0 HZ. NOISE POWER IS  85.275 DB//1UPA OR 3.369E  8 UPA**2.
 1280.0 TO 2560.0 HZ. NOISE POWER IS  83.862 DB//1UPA OR 2.433E  8 UPA**2.
  800.0 TO 1600.0 HZ. NOISE POWER IS  85.074 DB//1UPA OR 3.217E  8 UPA**2.
 1600.0 TO 3200.0 HZ. NOISE POWER IS  84.543 DB//1UPA OR 2.846E  8 UPA**2.
```

```
Q2A15DH343. M/V ARCTIC. 0915 6-28-82. 20 M H56

  320.0 TO16000.0 HZ. NOISE POWER IS  90.541 DB//1UPA OR 1.133E  9 UPA**2.
 3200.0 TO16000.0 HZ. NOISE POWER IS  84.214 DB//1UPA OR 2.639E  8 UPA**2.
 6400.0 TO16000.0 HZ. NOISE POWER IS  72.279 DB//1UPA OR 1.690E  7 UPA**2.
  320.0 TO  640.0 HZ. NOISE POWER IS  81.689 DB//1UPA OR 1.475E  8 UPA**2.
  640.0 TO 1280.0 HZ. NOISE POWER IS  85.605 DB//1UPA OR 3.635E  8 UPA**2.
 1280.0 TO 2560.0 HZ. NOISE POWER IS  83.884 DB//1UPA OR 2.446E  8 UPA**2.
 2560.0 TO 5120.0 HZ. NOISE POWER IS  85.053 DB//1UPA OR 3.201E  8 UPA**2.
 5120.0 TO10240.0 HZ. NOISE POWER IS  77.421 DB//1UPA OR 5.522E  7 UPA**2.
 3200.0 TO 6400.0 HZ. NOISE POWER IS  83.927 DB//1UPA OR 2.470E  8 UPA**2.
 6400.0 TO12800.0 HZ. NOISE POWER IS  72.133 DB//1UPA OR 1.634E  7 UPA**2.
```

Table A5. Band level analyses at 10:20, 28 June, 1982.

```
QAB15DH122. AMBIENT NOISE. 1020. 28 JUNE 82

FREQUENCY RANGE          BAND LEVEL
  FROM      TO        DB RE
     (HZ)              1UPA    UPA**2

   320.0 16000.0       90.5   1.118E  9
  3200.0 16000.0       83.8   2.389E  8
  6400.0 16000.0       73.2   2.104E  7
   320.0   640.0       81.6   1.435E  8
   640.0  1280.0       85.2   3.350E  8
  1280.0  2560.0       85.1   3.249E  8
  2560.0  5120.0       83.9   2.481E  8
  5120.0 10240.0       78.0   6.321E  7
  3200.0  6400.0       83.4   2.178E  8
  6400.0 12800.0       73.0   1.984E  7

QAB13DH122. AMBIENT NOISE. 1020. 28 JUNE 82

FREQUENCY RANGE          BAND LEVEL
  FROM      TO        DB RE
     (HZ)              1UPA    UPA**2

    80.0  4000.0       90.4   1.088E  9
   800.0  4000.0       88.4   6.933E  8
  1600.0  4000.0       85.5   3.578E  8
    80.0   160.0       76.8   4.756E  7
   160.0   320.0       80.9   1.239E  8
   320.0   640.0       81.9   1.553E  8
   640.0  1280.0       84.9   3.070E  8
  1280.0  2560.0       84.7   2.930E  8
   800.0  1600.0       85.3   3.356E  8
  1600.0  3200.0       84.5   2.797E  8

QAB11DB122. AMBIENT NOISE. 1020. 28 JUNE 82

FREQUENCY RANGE          BAND LEVEL
  FROM      TO        DB RE
     (HZ)              1UPA    UPA**2

    10.0   500.0       89.5   8.819E  8
   100.0   500.0       88.2   6.605E  8
   200.0   500.0       85.8   3.776E  8
    10.0  1000.0       90.4   1.097E  9
   100.0  1000.0       89.4   8.751E  8
   200.0  1000.0       87.7   5.923E  8
    10.0    20.0       72.3   1.712E  7
    20.0    40.0       69.6   9.023E  6
    40.0    80.0       80.2   1.052E  8
    80.0   160.0       84.5   2.798E  8
   160.0   320.0       84.5   2.835E  8
   320.0   640.0       84.3   2.699E  8
   100.0   200.0       84.5   2.828E  8
   200.0   400.0       84.3   2.695E  8
   400.0   800.0       84.0   2.526E  8
```

Table A6. Band level analyses at 12:22, 28 June, 1982.

```
QAB11DB256. BEARDED SEAL PLUS. 1222. 28 JUNE 82

FREQUENCY RANGE          BAND LEVEL
  FROM      TO        DB RE
     (HZ)              1UPA    UPA**2

    10.0   500.0       89.6   9.087E  8
   100.0   500.0       88.0   6.368E  8
   200.0   500.0       86.3   4.307E  8
    10.0  1000.0       92.7   1.846E  9
   100.0  1000.0       92.0   1.574E  9
   200.0  1000.0       91.4   1.368E  9
    10.0    20.0       80.4   1.089E  8
    20.0    40.0       72.2   1.665E  7
    40.0    80.0       79.2   8.342E  7
    80.0   160.0       82.9   1.964E  8
   160.0   320.0       85.2   3.333E  8
   320.0   640.0       87.4   5.477E  8
   100.0   200.0       83.1   2.061E  8
   200.0   400.0       85.1   3.257E  8
   400.0   800.0       88.9   7.713E  8

QAB13DH256. BEARDED SEAL PLUS. 1222. 28 JUNE 82

FREQUENCY RANGE          BAND LEVEL
  FROM      TO        DB RE
     (HZ)              1UPA    UPA**2

    80.0  4000.0       91.9   1.553E  9
   800.0  4000.0       90.8   1.201E  9
  1600.0  4000.0       88.9   7.848E  8
    80.0   160.0       77.2   5.198E  7
   160.0   320.0       81.8   1.512E  8
   320.0   640.0       80.4   1.093E  8
   640.0  1280.0       82.0   1.592E  8
  1280.0  2560.0       89.9   9.699E  8
   800.0  1600.0       86.2   4.158E  8
  1600.0  3200.0       88.6   7.291E  8

QAB15DH256. BEARDED SEAL PLUS. 1222. 28 JUNE 82

FREQUENCY RANGE          BAND LEVEL
  FROM      TO        DB RE
     (HZ)              1UPA    UPA**2

   320.0 16000.0       91.9   1.540E  9
  3200.0 16000.0       84.1   2.550E  8
  6400.0 16000.0       75.1   3.230E  7
   320.0   640.0       80.9   1.232E  8
   640.0  1280.0       81.7   1.468E  8
  1280.0  2560.0       89.8   9.580E  8
  2560.0  5120.0       83.2   2.078E  8
  5120.0 10240.0       80.0   1.008E  8
  3200.0  6400.0       83.5   2.227E  8
  6400.0 12800.0       74.9   3.093E  7
```

Table A7. Band level analyses at 12:15, 28 June, 1982.

```
02B11DH160. M/V ARCTIC. 1215. 28 JUNE 82. 20 M H56

FROM    10.0 TO   500.0 HZ. THE NOISE POWER IS  86.822 DB//1UPA
FROM   100.0 TO   500.0 HZ. THE NOISE POWER IS  84.355 DB//1UPA
FROM   200.0 TO   500.0 HZ. THE NOISE POWER IS  83.164 DB//1UPA
FROM    10.0 TO  1000.0 HZ. THE NOISE POWER IS  88.236 DB//1UPA
FROM   100.0 TO  1000.0 HZ. THE NOISE POWER IS  86.607 DB//1UPA
FROM   200.0 TO  1000.0 HZ. THE NOISE POWER IS  85.937 DB//1UPA
FROM    10.0 TO    20.0 HZ. THE NOISE POWER IS  81.332 DB//1UPA
FROM    20.0 TO    40.0 HZ. THE NOISE POWER IS  75.658 DB//1UPA
FROM    40.0 TO    80.0 HZ. THE NOISE POWER IS  73.618 DB//1UPA
FROM    80.0 TO   160.0 HZ. THE NOISE POWER IS  77.377 DB//1UPA
FROM   160.0 TO   320.0 HZ. THE NOISE POWER IS  80.028 DB//1UPA
FROM   320.0 TO   640.0 HZ. THE NOISE POWER IS  82.892 DB//1UPA
FROM   100.0 TO   200.0 HZ. THE NOISE POWER IS  78.153 DB//1UPA
FROM   200.0 TO   400.0 HZ. THE NOISE POWER IS  80.915 DB//1UPA
FROM   400.0 TO   800.0 HZ. THE NOISE POWER IS  83.284 DB//1UPA

02B13DH160. M/V ARCTIC. 1215. 28 JUNE 82. 20 M H56

FROM    80.0 TO  4000.0 HZ. THE NOISE POWER IS  88.915 DB//1UPA
FROM   800.0 TO  4000.0 HZ. THE NOISE POWER IS  85.835 DB//1UPA
FROM  1600.0 TO  4000.0 HZ. THE NOISE POWER IS  83.047 DB//1UPA
FROM    80.0 TO   160.0 HZ. THE NOISE POWER IS  77.917 DB//1UPA
FROM   160.0 TO   320.0 HZ. THE NOISE POWER IS  80.487 DB//1UPA
FROM   320.0 TO   640.0 HZ. THE NOISE POWER IS  81.343 DB//1UPA
FROM   640.0 TO  1280.0 HZ. THE NOISE POWER IS  83.078 DB//1UPA
FROM  1280.0 TO  2560.0 HZ. THE NOISE POWER IS  82.320 DB//1UPA
FROM   800.0 TO  1600.0 HZ. THE NOISE POWER IS  82.589 DB//1UPA
FROM  1600.0 TO  3200.0 HZ. THE NOISE POWER IS  81.973 DB//1UPA

02B15DH160. M/V ARCTIC. 1215. 28 JUNE 82. 20 M H56

FROM   320.0 TO 16000.0 HZ. THE NOISE POWER IS  88.448 DB//1UPA
FROM  3200.0 TO 16000.0 HZ. THE NOISE POWER IS  82.359 DB//1UPA
FROM  6400.0 TO 16000.0 HZ. THE NOISE POWER IS  73.770 DB//1UPA
FROM   320.0 TO   640.0 HZ. THE NOISE POWER IS  81.354 DB//1UPA
FROM   640.0 TO  1280.0 HZ. THE NOISE POWER IS  82.686 DB//1UPA
FROM  1280.0 TO  2560.0 HZ. THE NOISE POWER IS  81.897 DB//1UPA
FROM  2560.0 TO  5120.0 HZ. THE NOISE POWER IS  81.810 DB//1UPA
FROM  5120.0 TO 10240.0 HZ. THE NOISE POWER IS  78.370 DB//1UPA
FROM  3200.0 TO  6400.0 HZ. THE NOISE POWER IS  81.713 DB//1UPA
FROM  6400.0 TO 12800.0 HZ. THE NOISE POWER IS  73.628 DB//1UPA
```

Table A8. Band level analyses at 14:31, 28 June, 1982.

```
02B11DB224. M/V ARCTIC. 1431. 28 JUNE 82. 20 M BENDER

FROM    10.0 TO   500.0 HZ. THE NOISE POWER IS  93.013 DB//1UPA
FROM   100.0 TO   500.0 HZ. THE NOISE POWER IS  92.127 DB//1UPA
FROM   200.0 TO   500.0 HZ. THE NOISE POWER IS  90.006 DB//1UPA
FROM    10.0 TO  1000.0 HZ. THE NOISE POWER IS  94.283 DB//1UPA
FROM   100.0 TO  1000.0 HZ. THE NOISE POWER IS  93.640 DB//1UPA
FROM   200.0 TO  1000.0 HZ. THE NOISE POWER IS  92.256 DB//1UPA
FROM    10.0 TO    20.0 HZ. THE NOISE POWER IS  69.522 DB//1UPA
FROM    20.0 TO    40.0 HZ. THE NOISE POWER IS  74.463 DB//1UPA
FROM    40.0 TO    80.0 HZ. THE NOISE POWER IS  82.245 DB//1UPA
FROM    80.0 TO   160.0 HZ. THE NOISE POWER IS  87.539 DB//1UPA
FROM   160.0 TO   320.0 HZ. THE NOISE POWER IS  88.891 DB//1UPA
FROM   320.0 TO   640.0 HZ. THE NOISE POWER IS  88.211 DB//1UPA
FROM   100.0 TO   200.0 HZ. THE NOISE POWER IS  87.998 DB//1UPA
FROM   200.0 TO   400.0 HZ. THE NOISE POWER IS  88.930 DB//1UPA
FROM   400.0 TO   800.0 HZ. THE NOISE POWER IS  87.587 DB//1UPA

02B13DH224. M/V ARCTIC. 1431. 28 JUNE 82. 20 M H56

FROM    80.0 TO  4000.0 HZ. THE NOISE POWER IS  95.166 DB//1UPA
FROM   800.0 TO  4000.0 HZ. THE NOISE POWER IS  93.703 DB//1UPA
FROM  1600.0 TO  4000.0 HZ. THE NOISE POWER IS  90.856 DB//1UPA
FROM    80.0 TO   160.0 HZ. THE NOISE POWER IS  80.438 DB//1UPA
FROM   160.0 TO   320.0 HZ. THE NOISE POWER IS  84.453 DB//1UPA
FROM   320.0 TO   640.0 HZ. THE NOISE POWER IS  86.289 DB//1UPA
FROM   640.0 TO  1280.0 HZ. THE NOISE POWER IS  89.334 DB//1UPA
FROM  1280.0 TO  2560.0 HZ. THE NOISE POWER IS  89.706 DB//1UPA
FROM   800.0 TO  1600.0 HZ. THE NOISE POWER IS  90.522 DB//1UPA
FROM  1600.0 TO  3200.0 HZ. THE NOISE POWER IS  88.958 DB//1UPA

02B15DH224. M/V ARCTIC. 1431. 28 JUNE 82. 20 M H56

FROM   320.0 TO 16000.0 HZ. THE NOISE POWER IS  94.570 DB//1UPA
FROM  3200.0 TO 16000.0 HZ. THE NOISE POWER IS  88.728 DB//1UPA
FROM  6400.0 TO 16000.0 HZ. THE NOISE POWER IS  76.926 DB//1UPA
FROM   320.0 TO   640.0 HZ. THE NOISE POWER IS  86.009 DB//1UPA
FROM   640.0 TO  1280.0 HZ. THE NOISE POWER IS  89.193 DB//1UPA
FROM  1280.0 TO  2560.0 HZ. THE NOISE POWER IS  88.322 DB//1UPA
FROM  2560.0 TO  5120.0 HZ. THE NOISE POWER IS  89.035 DB//1UPA
FROM  5120.0 TO 10240.0 HZ. THE NOISE POWER IS  81.759 DB//1UPA
FROM  3200.0 TO  6400.0 HZ. THE NOISE POWER IS  88.431 DB//1UPA
FROM  6400.0 TO 12800.0 HZ. THE NOISE POWER IS  76.766 DB//1UPA
```

Table A9. Band level analyses at 16:11, 28 June, 1982.

```
QAB11DB580. M/V ARCTIC. 1611. 28 JUNE 82

FREQUENCY RANGE          BAND LEVEL
  FROM      TO       DB RE
    (HZ)              1UPA    UPA**2

   10.0    500.0     97.6   5.789E  9
  100.0    500.0     96.7   4.650E  9
  200.0    500.0     96.1   4.035E  9
   10.0   1000.0    100.0   1.003E 10
  100.0   1000.0     99.5   8.888E  9
  200.0   1000.0     99.2   8.273E  9
   10.0     20.0     87.5   5.598E  8
   20.0     40.0     83.7   2.349E  8
   40.0     80.0     83.5   2.246E  8
   80.0    160.0     87.2   5.193E  8
  160.0    320.0     92.5   1.763E  9
  320.0    640.0     96.2   4.165E  9
  100.0    200.0     87.9   6.157E  8
  200.0    400.0     94.6   2.864E  9
  400.0    800.0     95.9   3.898E  9
```

```
QAB13DH580. M/V ARCTIC. 1611. 28 JUNE 82

FREQUENCY RANGE          BAND LEVEL
  FROM      TO       DB RE
    (HZ)              1UPA    UPA**2

   80.0   4000.0    105.6   3.626E 10
  800.0   4000.0    104.9   3.081E 10
 1600.0   4000.0    103.3   2.132E 10
   80.0    160.0     83.8   2.424E  8
  160.0    320.0     89.4   8.667E  8
  320.0    640.0     95.0   3.176E  9
  640.0   1280.0     98.2   6.640E  9
 1280.0   2560.0    102.3   1.691E 10
  800.0   1600.0     99.8   9.486E  9
 1600.0   3200.0    102.3   1.685E 10
```

```
QAB15DH580. M/V ARCTIC. 1611. 28 JUNE 82

FREQUENCY RANGE          BAND LEVEL
  FROM      TO       DB RE
    (HZ)              1UPA    UPA**2

  320.0  16000.0    106.0   3.960E 10
 3200.0  16000.0     99.5   8.975E  9
 6400.0  16000.0     79.2   8.293E  7
  320.0    640.0     95.1   3.211E  9
  640.0   1280.0     98.0   6.306E  9
 1280.0   2560.0    102.4   1.736E 10
 2560.0   5120.0    100.9   1.239E 10
 5120.0  10240.0     85.1   3.237E  8
 3200.0   6400.0     99.5   8.892E  9
 6400.0  12800.0     78.8   7.566E  7
```

Table A10. Band level analyses at 16:56, 28 June, 1982.

```
03A11DB040. M/V ARCTIC. 3.4 NM. 1656.5. 28 JUNE 82

FROM    10.0 TO    500.0 HZ. THE NOISE POWER IS 105.249 DB//1UPA
FROM   100.0 TO    500.0 HZ. THE NOISE POWER IS 103.553 DB//1UPA
FROM   200.0 TO    500.0 HZ. THE NOISE POWER IS 100.146 DB//1UPA
FROM    10.0 TO   1000.0 HZ. THE NOISE POWER IS 105.808 DB//1UPA
FROM   100.0 TO   1000.0 HZ. THE NOISE POWER IS 104.355 DB//1UPA
FROM   200.0 TO   1000.0 HZ. THE NOISE POWER IS 101.744 DB//1UPA
FROM    10.0 TO     20.0 HZ. THE NOISE POWER IS  94.126 DB//1UPA
FROM    20.0 TO     40.0 HZ. THE NOISE POWER IS  90.571 DB//1UPA
FROM    40.0 TO     80.0 HZ. THE NOISE POWER IS  95.685 DB//1UPA
FROM    80.0 TO    160.0 HZ. THE NOISE POWER IS 101.158 DB//1UPA
FROM   160.0 TO    320.0 HZ. THE NOISE POWER IS  99.379 DB//1UPA
FROM   320.0 TO    640.0 HZ. THE NOISE POWER IS  97.895 DB//1UPA
FROM   100.0 TO    200.0 HZ. THE NOISE POWER IS 100.906 DB//1UPA
FROM   200.0 TO    400.0 HZ. THE NOISE POWER IS  98.885 DB//1UPA
FROM   400.0 TO    800.0 HZ. THE NOISE POWER IS  97.352 DB//1UPA
```

```
03A13DH040. M/V ARCTIC. 3.4 NM. 1656.5. 28 JUNE 82

FROM    80.0 TO   4000.0 HZ. THE NOISE POWER IS 103.653 DB//1UPA
FROM   800.0 TO   4000.0 HZ. THE NOISE POWER IS  99.744 DB//1UPA
FROM  1600.0 TO   4000.0 HZ. THE NOISE POWER IS  96.460 DB//1UPA
FROM    80.0 TO    160.0 HZ. THE NOISE POWER IS  95.536 DB//1UPA
FROM   160.0 TO    320.0 HZ. THE NOISE POWER IS  96.108 DB//1UPA
FROM   320.0 TO    640.0 HZ. THE NOISE POWER IS  97.178 DB//1UPA
FROM   640.0 TO   1280.0 HZ. THE NOISE POWER IS  95.886 DB//1UPA
FROM  1280.0 TO   2560.0 HZ. THE NOISE POWER IS  96.806 DB//1UPA
FROM   800.0 TO   1600.0 HZ. THE NOISE POWER IS  96.991 DB//1UPA
FROM  1600.0 TO   3200.0 HZ. THE NOISE POWER IS  95.808 DB//1UPA
```

```
03A15DH040. M/V ARCTIC. 3.4 NM. 1656.5. 28 JUNE 82

FROM   320.0 TO  16000.0 HZ. THE NOISE POWER IS 102.795 DB//1UPA
FROM  3200.0 TO  16000.0 HZ. THE NOISE POWER IS  92.834 DB//1UPA
FROM  6400.0 TO  16000.0 HZ. THE NOISE POWER IS  83.807 DB//1UPA
FROM   320.0 TO    640.0 HZ. THE NOISE POWER IS  96.983 DB//1UPA
FROM   640.0 TO   1280.0 HZ. THE NOISE POWER IS  95.989 DB//1UPA
FROM  1280.0 TO   2560.0 HZ. THE NOISE POWER IS  98.249 DB//1UPA
FROM  2560.0 TO   5120.0 HZ. THE NOISE POWER IS  94.637 DB//1UPA
FROM  5120.0 TO  10240.0 HZ. THE NOISE POWER IS  86.647 DB//1UPA
FROM  3200.0 TO   6400.0 HZ. THE NOISE POWER IS  92.253 DB//1UPA
FROM  6400.0 TO  12800.0 HZ. THE NOISE POWER IS  83.663 DB//1UPA
```

Table A11. Band level analyses at 17:05, 28 June, 1982.

```
03A11DB147. M/V ARCTIC. 1.58 NM. 1705. 28 JUNE 82

FROM    10.0 TO   500.0 HZ. THE NOISE POWER IS 114.929 DB//1UPA
FROM   100.0 TO   500.0 HZ. THE NOISE POWER IS 111.709 DB//1UPA
FROM   200.0 TO   500.0 HZ. THE NOISE POWER IS 109.032 DB//1UPA
FROM    10.0 TO  1000.0 HZ. THE NOISE POWER IS 115.601 DB//1UPA
FROM   100.0 TO  1000.0 HZ. THE NOISE POWER IS 113.016 DB//1UPA
FROM   200.0 TO  1000.0 HZ. THE NOISE POWER IS 111.207 DB//1UPA
FROM    10.0 TO    20.0 HZ. THE NOISE POWER IS 100.761 DB//1UPA
FROM    20.0 TO    40.0 HZ. THE NOISE POWER IS 104.768 DB//1UPA
FROM    40.0 TO    80.0 HZ. THE NOISE POWER IS 110.297 DB//1UPA
FROM    80.0 TO   160.0 HZ. THE NOISE POWER IS 108.529 DB//1UPA
FROM   160.0 TO   320.0 HZ. THE NOISE POWER IS 107.692 DB//1UPA
FROM   320.0 TO   640.0 HZ. THE NOISE POWER IS 107.574 DB//1UPA
FROM   100.0 TO   200.0 HZ. THE NOISE POWER IS 108.339 DB//1UPA
FROM   200.0 TO   400.0 HZ. THE NOISE POWER IS 108.058 DB//1UPA
FROM   400.0 TO   800.0 HZ. THE NOISE POWER IS 107.066 DB//1UPA


03A13DH147. M/V ARCTIC. 1.58 NM. 1705. 28 JUNE 82

FROM    80.0 TO  4000.0 HZ. THE NOISE POWER IS 111.483 DB//1UPA
FROM   800.0 TO  4000.0 HZ. THE NOISE POWER IS 107.785 DB//1UPA
FROM  1600.0 TO  4000.0 HZ. THE NOISE POWER IS 104.908 DB//1UPA
FROM    80.0 TO   160.0 HZ. THE NOISE POWER IS 103.810 DB//1UPA
FROM   160.0 TO   320.0 HZ. THE NOISE POWER IS 104.582 DB//1UPA
FROM   320.0 TO   640.0 HZ. THE NOISE POWER IS 103.472 DB//1UPA
FROM   640.0 TO  1280.0 HZ. THE NOISE POWER IS 104.206 DB//1UPA
FROM  1280.0 TO  2560.0 HZ. THE NOISE POWER IS 104.569 DB//1UPA
FROM   800.0 TO  1600.0 HZ. THE NOISE POWER IS 104.638 DB//1UPA
FROM  1600.0 TO  3200.0 HZ. THE NOISE POWER IS 104.231 DB//1UPA


03A15DH147. M/V ARCTIC. 1.58 NM. 1705. 28 JUNE 82

FROM   320.0 TO 16000.0 HZ. THE NOISE POWER IS 109.991 DB//1UPA
FROM  3200.0 TO 16000.0 HZ. THE NOISE POWER IS 100.596 DB//1UPA
FROM  6400.0 TO 16000.0 HZ. THE NOISE POWER IS  90.283 DB//1UPA
FROM   320.0 TO   640.0 HZ. THE NOISE POWER IS 103.711 DB//1UPA
FROM   640.0 TO  1280.0 HZ. THE NOISE POWER IS 104.134 DB//1UPA
FROM  1280.0 TO  2560.0 HZ. THE NOISE POWER IS 105.096 DB//1UPA
FROM  2560.0 TO  5120.0 HZ. THE NOISE POWER IS 101.913 DB//1UPA
FROM  5120.0 TO 10240.0 HZ. THE NOISE POWER IS  93.466 DB//1UPA
FROM  3200.0 TO  6400.0 HZ. THE NOISE POWER IS 100.172 DB//1UPA
FROM  6400.0 TO 12800.0 HZ. THE NOISE POWER IS  89.855 DB//1UPA
```

Table A12. Band level analyses at 17:15, 28 June, 1982.

```
03A11DB296. M/V ARCTIC. JUST BEFORE STOPPING. 1715

FREQUENCY RANGE       BAND LEVEL
  FROM     TO      DB RE
    (HZ)            1UPA    UPA**2

   10.0   500.0   127.2   5.303E 12
  100.0   500.0   124.9   3.101E 12
  200.0   500.0   120.7   1.164E 12
   10.0  1000.0   127.8   6.042E 12
  100.0  1000.0   125.8   3.841E 12
  200.0  1000.0   122.8   1.904E 12
   10.0    20.0   114.8   3.048E 11
   20.0    40.0   114.0   2.519E 11
   40.0    80.0   121.4   1.395E 12
   80.0   160.0   122.9   1.947E 12
  160.0   320.0   120.2   1.043E 12
  320.0   640.0   118.5   7.106E 11
  100.0   200.0   122.9   1.937E 12
  200.0   400.0   120.2   1.053E 12
  400.0   800.0   117.8   6.086E 11
03A13DH296. M/V ARCTIC. JUST BEFORE STOPPING. 1715

FREQUENCY RANGE       BAND LEVEL
  FROM     TO      DB RE
    (HZ)            1UPA    UPA**2

   80.0  4000.0   125.2   3.342E 12
  800.0  4000.0   119.5   8.843E 11
 1600.0  4000.0   116.4   4.350E 11
   80.0   160.0   119.4   8.638E 11
  160.0   320.0   119.3   8.590E 11
  320.0   640.0   117.7   5.870E 11
  640.0  1280.0   116.6   4.599E 11
 1280.0  2560.0   116.3   4.314E 11
  800.0  1600.0   116.5   4.493E 11
 1600.0  3200.0   115.8   3.776E 11

03A15DH296. M/V ARCTIC. JUST BEFORE STOPPING. 1715

FREQUENCY RANGE       BAND LEVEL
  FROM     TO      DB RE
    (HZ)            1UPA    UPA**2

  320.0 16000.0   122.4   1.748E 12
 3200.0 16000.0   113.6   2.277E 11
 6400.0 16000.0   107.8   5.979E 10
  320.0   640.0   117.7   5.828E 11
  640.0  1280.0   116.0   4.011E 11
 1280.0  2560.0   116.4   4.388E 11
 2560.0  5120.0   113.7   2.332E 11
 5120.0 10240.0   108.3   6.720E 10
 3200.0  6400.0   112.3   1.679E 11
 6400.0 12800.0   106.8   4.808E 10
```

Table A13. Band level analyses at 17:16, 28 June, 1982.

Q3A11DB305. M/V ARCTIC. SHIP IS STOPPED. 1716 28 JUN

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
10.0	500.0	120.1	1.023E 12
100.0	500.0	118.0	6.268E 11
200.0	500.0	112.6	1.830E 11
10.0	1000.0	120.6	1.144E 12
100.0	1000.0	118.7	7.477E 11
200.0	1000.0	114.8	3.039E 11
10.0	20.0	108.5	7.070E 10
20.0	40.0	107.0	5.051E 10
40.0	80.0	112.1	1.623E 11
80.0	160.0	116.5	4.476E 11
160.0	320.0	113.0	2.013E 11
320.0	640.0	111.8	1.507E 11
100.0	200.0	116.5	4.438E 11
200.0	400.0	111.6	1.461E 11
400.0	800.0	111.0	1.253E 11

Q3A13DH305. M/V ARCTIC. SHIP IS STOPPED. 1716 28 JUN

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
80.0	4000.0	119.3	8.432E 11
800.0	4000.0	113.7	2.336E 11
1600.0	4000.0	109.8	9.634E 10
80.0	160.0	114.7	2.925E 11
160.0	320.0	111.7	1.463E 11
320.0	640.0	111.3	1.349E 11
640.0	1280.0	111.1	1.288E 11
1280.0	2560.0	110.3	1.078E 11
800.0	1600.0	111.4	1.372E 11
1600.0	3200.0	109.3	8.419E 10

Q3A15DH305. M/V ARCTIC. SHIP IS STOPPED. 1716 28 JUN

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
320.0	16000.0	116.5	4.450E 11
3200.0	16000.0	105.8	3.788E 10
6400.0	16000.0	98.5	7.108E 9
320.0	640.0	111.6	1.453E 11
640.0	1280.0	111.1	1.276E 11
1280.0	2560.0	110.5	1.122E 11
2560.0	5120.0	106.9	4.861E 10
5120.0	10240.0	99.5	8.895E 9
3200.0	6400.0	104.9	3.077E 10
6400.0	12800.0	97.9	6.151E 9

Table A14. Band level analyses at 17:42, 28 June, 1982.

Q3B11DB023. M/V ARCTIC. SHIP BACKING DOWN. 1742

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
10.0	500.0	135.4	3.434E 13
100.0	500.0	133.5	2.242E 13
200.0	500.0	129.8	9.453E 12
10.0	1000.0	135.9	3.876E 13
100.0	1000.0	134.3	2.684E 13
200.0	1000.0	131.4	1.387E 13
10.0	20.0	119.8	9.659E 11
20.0	40.0	125.0	3.189E 12
40.0	80.0	128.1	6.429E 12
80.0	160.0	130.9	1.234E 13
160.0	320.0	128.8	7.522E 12
320.0	640.0	127.5	5.572E 12
100.0	200.0	131.1	1.297E 13
200.0	400.0	129.4	8.683E 12
400.0	800.0	125.9	3.871E 12

Q3B13DH023. M/V ARCTIC. SHIP BACKING DOWN. 1742

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
80.0	4000.0	132.4	1.754E 13
800.0	4000.0	125.7	3.753E 12
1600.0	4000.0	120.1	1.030E 12
80.0	160.0	125.7	3.706E 12
160.0	320.0	127.2	5.269E 12
320.0	640.0	125.8	3.771E 12
640.0	1280.0	125.0	3.144E 12
1280.0	2560.0	121.3	1.346E 12
800.0	1600.0	124.4	2.723E 12
1600.0	3200.0	119.6	9.062E 11

Q3B15DH023. M/V ARCTIC. SHIP BACKING DOWN. 1742

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
320.0	16000.0	129.4	8.614E 12
3200.0	16000.0	117.3	5.392E 11
6400.0	16000.0	110.5	1.119E 11
320.0	640.0	125.2	3.294E 12
640.0	1280.0	124.7	2.968E 12
1280.0	2560.0	122.0	1.594E 12
2560.0	5120.0	117.5	5.656E 11
5120.0	10240.0	111.6	1.434E 11
3200.0	6400.0	116.3	4.273E 11
6400.0	12800.0	109.5	8.932E 10

Table A15. Band level analyses at 17:49, 28 June, 1982.

Q3B11DB111, M/V ARCTIC, PROPELLER CPA, 1749, 28 JUNE

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
10.0	500.0	133.2	2.087E 13
100.0	500.0	130.8	1.201E 13
200.0	500.0	129.8	9.573E 12
10.0	1000.0	134.8	3.038E 13
100.0	1000.0	133.3	2.152E 13
200.0	1000.0	132.8	1.909E 13
10.0	20.0	118.8	7.542E 11
20.0	40.0	119.9	9.825E 11
40.0	80.0	128.0	6.381E 12
80.0	160.0	123.4	2.203E 12
160.0	320.0	128.7	7.368E 12
320.0	640.0	128.5	7.108E 12
100.0	200.0	123.9	2.437E 12
200.0	400.0	128.9	7.750E 12
400.0	800.0	129.6	9.114E 12

Q3B15DH111, M/V ARCTIC, PROPELLER CPA, 1749, 28 JUNE

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
320.0	16000.0	132.3	1.697E 13
3200.0	16000.0	123.6	2.284E 12
6400.0	16000.0	115.6	3.611E 11
320.0	640.0	124.6	2.862E 12
640.0	1280.0	128.3	6.719E 12
1280.0	2560.0	126.0	3.969E 12
2560.0	5120.0	124.4	2.732E 12
5120.0	10240.0	117.5	5.656E 11
3200.0	6400.0	122.8	1.923E 12
6400.0	12800.0	114.9	3.122E 11

Q3B13DH111, M/V ARCTIC, PROPELLER CPA, 1749, 28 JUNE

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
80.0	4000.0	132.8	1.914E 13
800.0	4000.0	130.3	1.069E 13
1600.0	4000.0	126.8	4.789E 12
80.0	160.0	117.5	5.582E 11
160.0	320.0	124.3	2.678E 12
320.0	640.0	124.9	3.095E 12
640.0	1280.0	128.4	6.915E 12
1280.0	2560.0	126.0	3.978E 12
800.0	1600.0	127.7	5.905E 12
1600.0	3200.0	126.0	4.025E 12

Table A16. Band level analyses at 18:04, 28 June, 1982.

Q3B11DB322, M/V ARCTIC, BIG REVERSE NOISES, 1804

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
10.0	500.0	138.0	6.240E 13
100.0	500.0	132.7	1.877E 13
200.0	500.0	131.1	1.286E 13
10.0	1000.0	138.1	6.484E 13
100.0	1000.0	133.3	2.121E 13
200.0	1000.0	131.8	1.531E 13
10.0	20.0	129.0	8.001E 12
20.0	40.0	133.2	2.102E 13
40.0	80.0	130.0	9.938E 12
80.0	160.0	129.6	9.205E 12
160.0	320.0	128.7	7.494E 12
320.0	640.0	128.9	7.703E 12
100.0	200.0	127.7	5.906E 12
200.0	400.0	129.7	9.257E 12
400.0	800.0	127.2	5.275E 12

Q3B13DH322, M/V ARCTIC, BIG REVERSE NOISES, 1804

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
80.0	4000.0	132.4	1.718E 13
800.0	4000.0	126.9	4.931E 12
1600.0	4000.0	123.7	2.324E 12
80.0	160.0	125.2	3.305E 12
160.0	320.0	127.6	5.807E 12
320.0	640.0	123.9	2.469E 12
640.0	1280.0	123.9	2.465E 12
1280.0	2560.0	123.3	2.153E 12
800.0	1600.0	124.2	2.607E 12
1600.0	3200.0	122.7	1.877E 12

Q3B15DH322, M/V ARCTIC, BIG REVERSE NOISES, 1804

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
320.0	16000.0	129.0	7.882E 12
3200.0	16000.0	122.3	1.705E 12
6400.0	16000.0	116.7	4.625E 11
320.0	640.0	123.4	2.189E 12
640.0	1280.0	122.4	1.753E 12
1280.0	2560.0	122.5	1.788E 12
2560.0	5120.0	121.1	1.296E 12
5120.0	10240.0	118.4	6.992E 11
3200.0	6400.0	120.9	1.242E 12
6400.0	12800.0	116.0	4.013E 11

Table A17. Band level analyses at 20:36, 28 June, 1982.

Q6A11DB040. M/V ARCTIC GOING ASTERN. 2.6 NM. 2036

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
10.0	500.0	127.5	5.608E 12
100.0	500.0	125.7	3.675E 12
200.0	500.0	119.2	8.373E 11
10.0	1000.0	127.7	5.890E 12
100.0	1000.0	126.0	3.957E 12
200.0	1000.0	120.5	1.119E 12
10.0	20.0	97.9	6.184E 9
20.0	40.0	110.6	1.141E 11
40.0	80.0	120.8	1.191E 12
80.0	160.0	123.0	2.016E 12
160.0	320.0	122.6	1.832E 12
320.0	640.0	117.2	5.303E 11
100.0	200.0	124.5	2.838E 12
200.0	400.0	118.1	6.397E 11
400.0	800.0	116.0	4.024E 11

Q6A13DH040. M/V ARCTIC GOING ASTERN. 2.6 NM. 2036

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
80.0	4000.0	123.3	2.114E 12
800.0	4000.0	114.5	2.832E 11
1600.0	4000.0	109.7	9.260E 10
80.0	160.0	118.4	6.918E 11
160.0	320.0	118.9	7.686E 11
320.0	640.0	115.1	3.232E 11
640.0	1280.0	112.4	1.734E 11
1280.0	2560.0	111.1	1.302E 11
800.0	1600.0	112.8	1.906E 11
1600.0	3200.0	109.1	8.221E 10

Q6A15DH040. M/V ARCTIC GOING ASTERN. 2.6 NM. 2036

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
320.0	16000.0	118.8	7.555E 11
3200.0	16000.0	106.5	4.426E 10
6400.0	16000.0	100.1	1.034E 10
320.0	640.0	115.7	3.719E 11
640.0	1280.0	112.2	1.656E 11
1280.0	2560.0	111.9	1.563E 11
2560.0	5120.0	106.1	4.105E 10
5120.0	10240.0	102.8	1.908E 10
3200.0	6400.0	105.3	3.392E 10
6400.0	12800.0	100.0	9.896E 9

Table A18. Band level analyses at 20:39, 28 June, 1982.

Q6A11DB070. M/V ARCTIC GOING AHEAD. 2039. 28 JUNE

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
10.0	500.0	117.1	5.153E 11
100.0	500.0	113.9	2.432E 11
200.0	500.0	108.8	7.557E 10
10.0	1000.0	117.4	5.449E 11
100.0	1000.0	114.4	2.729E 11
200.0	1000.0	110.2	1.052E 11
10.0	20.0	89.4	8.731E 8
20.0	40.0	99.4	8.703E 9
40.0	80.0	112.4	1.736E 11
80.0	160.0	113.0	1.972E 11
160.0	320.0	110.0	9.988E 10
320.0	640.0	106.9	4.950E 10
100.0	200.0	112.2	1.677E 11
200.0	400.0	107.7	5.873E 10
400.0	800.0	106.0	4.002E 10

Q6A13DH070. M/V ARCTIC GOING AHEAD. 2039. 28 JUNE

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
80.0	4000.0	111.1	1.279E 11
800.0	4000.0	103.4	2.172E 10
1600.0	4000.0	98.0	6.378E 9
80.0	160.0	106.3	4.271E 10
160.0	320.0	105.7	3.710E 10
320.0	640.0	103.6	2.305E 10
640.0	1280.0	101.5	1.412E 10
1280.0	2560.0	99.4	8.737E 9
800.0	1600.0	101.9	1.535E 10
1600.0	3200.0	97.3	5.413E 9

Q6A15DH070. M/V ARCTIC GOING AHEAD. 2039. 28 JUNE

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
320.0	16000.0	106.8	4.800E 10
3200.0	16000.0	95.3	3.393E 9
6400.0	16000.0	86.8	4.742E 8
320.0	640.0	103.8	2.403E 10
640.0	1280.0	100.6	1.146E 10
1280.0	2560.0	99.2	8.232E 9
2560.0	5120.0	94.7	2.924E 9
5120.0	10240.0	91.2	1.327E 9
3200.0	6400.0	94.7	2.919E 9
6400.0	12800.0	86.7	4.660E 8

Table A19. Band level analyses at 11:13, 29 June, 1982.

```
Q8A11DB043, M/V ARCTIC GOING AHEAD, 1113, 29 JUNE

FREQUENCY RANGE      BAND LEVEL
  FROM      TO     DB RE
     (HZ)           1UPA   UPA**2

    10.0   500.0   103.7  2.330E 10
   100.0   500.0   103.5  2.241E 10
   200.0   500.0   101.9  1.544E 10
    10.0  1000.0   104.9  3.086E 10
   100.0  1000.0   104.8  2.997E 10
   200.0  1000.0   103.6  2.301E 10
    10.0    20.0    67.0  5.026E  6
    20.0    40.0    74.1  2.572E  7
    40.0    80.0    87.4  5.505E  8
    80.0   160.0    96.0  3.960E  9
   160.0   320.0   101.0  1.263E 10
   320.0   640.0    99.8  9.443E  9
   100.0   200.0    98.4  6.966E  9
   200.0   400.0   101.2  1.328E 10
   400.0   800.0    98.8  7.642E  9
Q8A13DH043, M/V ARCTIC GOING AHEAD, 1113, 29 JUNE

FREQUENCY RANGE      BAND LEVEL
  FROM      TO     DB RE
     (HZ)           1UPA   UPA**2

    80.0  4000.0   102.5  1.766E 10
   800.0  4000.0    97.8  5.963E  9
  1600.0  4000.0    91.7  1.489E  9
    80.0   160.0    89.8  9.464E  8
   160.0   320.0    96.0  3.945E  9
   320.0   640.0    97.2  5.204E  9
   640.0  1280.0    97.3  5.362E  9
  1280.0  2560.0    92.6  1.304E  9
   800.0  1600.0    96.5  4.475E  9
  1600.0  3200.0    91.3  1.336E  9

Q8A15DH043, M/V ARCTIC GOING AHEAD, 1113, 29 JUNE

FREQUENCY RANGE      BAND LEVEL
  FROM      TO     DB RE
     (HZ)           1UPA   UPA**2

   320.0 16000.0   100.6  1.150E 10
  3200.0 16000.0    83.6  2.292E  8
  6400.0 16000.0    72.5  1.797E  7
   320.0   640.0    96.7  4.689E  9
   640.0  1280.0    97.0  5.033E  9
  1280.0  2560.0    91.3  1.363E  9
  2560.0  5120.0    85.5  3.571E  8
  5120.0 10240.0    77.0  4.986E  7
  3200.0  6400.0    83.2  2.113E  8
  6400.0 12800.0    72.1  1.612E  7
```

Table A20. Band level analyses at 11:04, 30 June, 1982.

```
Q8B11DB180, M/V ARCTIC GOING AHEAD, 1104, 30 JUNE 82

FREQUENCY RANGE      BAND LEVEL
  FROM      TO     DB RE
     (HZ)           1UPA   UPA**2

    10.0   500.0    99.0  7.950E  9
   100.0   500.0    98.2  6.624E  9
   200.0   500.0    97.5  5.664E  9
    10.0  1000.0   100.5  1.115E 10
   100.0  1000.0    99.9  9.821E  9
   200.0  1000.0    99.5  8.361E  9
    10.0    20.0    65.2  3.295E  6
    20.0    40.0    69.8  9.488E  6
    40.0    80.0    90.1  1.027E  9
    80.0   160.0    89.3  8.445E  8
   160.0   320.0    94.9  3.066E  9
   320.0   640.0    96.4  4.400E  9
   100.0   200.0    89.8  9.596E  8
   200.0   400.0    96.2  4.195E  9
   400.0   800.0    95.9  3.892E  9
Q8B13DH180, M/V ARCTIC GOING AHEAD, 1104, 30 JUNE 82

FREQUENCY RANGE      BAND LEVEL
  FROM      TO     DB RE
     (HZ)           1UPA   UPA**2

    80.0  4000.0    96.7  4.696E  9
   800.0  4000.0    92.6  1.805E  9
  1600.0  4000.0    86.6  4.594E  8
    80.0   160.0    80.8  1.201E  8
   160.0   320.0    88.5  7.151E  8
   320.0   640.0    92.2  1.657E  9
   640.0  1280.0    91.5  1.423E  9
  1280.0  2560.0    87.8  6.080E  8
   800.0  1600.0    91.3  1.345E  9
  1600.0  3200.0    86.0  4.006E  8

Q8B15DH180, M/V ARCTIC GOING AHEAD, 1104, 30 JUNE 82

FREQUENCY RANGE      BAND LEVEL
  FROM      TO     DB RE
     (HZ)           1UPA   UPA**2

   320.0 16000.0    96.8  4.741E  9
  3200.0 16000.0    83.3  2.131E  8
  6400.0 16000.0    74.3  2.689E  7
   320.0   640.0    92.5  1.764E  9
   640.0  1280.0    92.5  1.774E  9
  1280.0  2560.0    89.3  8.598E  8
  2560.0  5120.0    84.8  3.049E  8
  5120.0 10240.0    73.7  2.369E  7
  3200.0  6400.0    82.7  1.862E  8
  6400.0 12800.0    72.7  1.873E  7
```

Table A21. Band level analyses at 16:08, 30 June, 1982.

```
Q2B11SB490, M/V ARCTIC, 1608, 28 JUNE, 2.5 M BENDER

FREQUENCY RANGE        BAND LEVEL
  FROM      TO      DB RE
     (HZ)            1UPA    UPA**2

   10.0    500.0    90.3   1.082E  9
  100.0    500.0    90.1   1.012E  9
  200.0    500.0    89.4   8.743E  8
   10.0   1000.0    93.0   1.974E  9
  100.0   1000.0    92.8   1.904E  9
  200.0   1000.0    92.5   1.767E  9
   10.0     20.0    74.5   2.844E  7
   20.0     40.0    68.3   6.743E  6
   40.0     80.0    72.3   1.691E  7
   80.0    160.0    80.1   1.016E  8
  160.0    320.0    85.8   3.778E  8
  320.0    640.0    88.9   7.836E  8
  100.0    200.0    81.4   1.377E  8
  200.0    400.0    87.6   5.760E  8
  400.0    800.0    88.5   7.001E  8
```

```
Q2B11DB490, M/V ARCTIC, 1608, 28 JUNE, 20 M BENDER

FREQUENCY RANGE        BAND LEVEL
  FROM      TO      DB RE
     (HZ)            1UPA    UPA**2

   10.0    500.0    96.2   4.192E  9
  100.0    500.0    95.3   3.374E  9
  200.0    500.0    93.2   2.087E  9
   10.0   1000.0    97.9   6.210E  9
  100.0   1000.0    97.3   5.392E  9
  200.0   1000.0    96.1   4.105E  9
   10.0     20.0    81.5   1.421E  8
   20.0     40.0    80.4   1.088E  8
   40.0     80.0    84.6   2.904E  8
   80.0    160.0    91.2   1.307E  9
  160.0    320.0    91.0   1.272E  9
  320.0    640.0    93.0   1.995E  9
  100.0    200.0    91.1   1.287E  9
  200.0    400.0    91.9   1.550E  9
  400.0    800.0    93.1   2.052E  9
```

Table A22. Band level analyses at 17:02, 28 June, 1982

```
Q3A11SB111, M/V ARCTIC, 1702, 28 JUNE, 2.5 M BENDER

FREQUENCY RANGE        BAND LEVEL
  FROM      TO      DB RE
     (HZ)            1UPA    UPA**2

   10.0    500.0   105.7   3.687E 10
  100.0    500.0   105.5   3.517E 10
  200.0    500.0   103.7   2.319E 10
   10.0   1000.0   107.3   5.370E 10
  100.0   1000.0   107.2   5.200E 10
  200.0   1000.0   106.0   4.002E 10
   10.0     20.0    84.5   2.831E  8
   20.0     40.0    81.1   1.298E  8
   40.0     80.0    88.7   7.367E  8
   80.0    160.0    99.2   8.293E  9
  160.0    320.0   102.4   1.719E 10
  320.0    640.0   101.3   1.340E 10
  100.0    200.0   100.8   1.198E 10
  200.0    400.0   103.0   1.996E 10
  400.0    800.0   100.0   9.923E  9
```

```
Q3A11DB111, M/V ARCTIC, 1702, 28 JUNE, 20 M BENDER

FREQUENCY RANGE        BAND LEVEL
  FROM      TO      DB RE
     (HZ)            1UPA    UPA**2

   10.0    500.0   108.4   6.913E 10
  100.0    500.0   106.5   4.433E 10
  200.0    500.0   104.3   2.673E 10
   10.0   1000.0   109.1   8.065E 10
  100.0   1000.0   107.5   5.586E 10
  200.0   1000.0   105.8   3.826E 10
   10.0     20.0    97.7   5.946E  9
   20.0     40.0    96.8   4.796E  9
   40.0     80.0    99.8   9.619E  9
   80.0    160.0   102.3   1.690E 10
  160.0    320.0   102.7   1.842E 10
  320.0    640.0   102.7   1.882E 10
  100.0    200.0   102.5   1.760E 10
  200.0    400.0   103.2   2.078E 10
  400.0    800.0   101.4   1.394E 10
```

Table A23. Band level analyses at 17:48, 28 June, 1982.

Q3B11SB095, M/V ARCTIC, SHIP BREAKING ICE, 1748, 2.5 M

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
10.0	500.0	127.1	5.140E 12
100.0	500.0	125.2	3.306E 12
200.0	500.0	122.4	1.749E 12
10.0	1000.0	128.0	6.369E 12
100.0	1000.0	126.6	4.535E 12
200.0	1000.0	124.7	2.978E 12
10.0	20.0	112.3	1.700E 11
20.0	40.0	113.2	2.102E 11
40.0	80.0	121.1	1.289E 12
80.0	160.0	121.5	1.412E 12
160.0	320.0	122.5	1.787E 12
320.0	640.0	119.1	8.048E 11
100.0	200.0	121.9	1.557E 12
200.0	400.0	122.1	1.616E 12
400.0	800.0	119.2	8.366E 11

Q3B11DB095, M/V ARCTIC, SHIP BREAKING ICE, 1748, 20 M

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
10.0	500.0	131.1	1.296E 13
100.0	500.0	128.6	7.291E 12
200.0	500.0	127.3	5.310E 12
10.0	1000.0	133.3	2.157E 13
100.0	1000.0	132.0	1.590E 13
200.0	1000.0	131.4	1.392E 13
10.0	20.0	118.3	6.692E 11
20.0	40.0	120.6	1.154E 12
40.0	80.0	125.1	3.219E 12
80.0	160.0	123.4	2.186E 12
160.0	320.0	124.7	2.952E 12
320.0	640.0	127.5	5.651E 12
100.0	200.0	123.0	1.981E 12
200.0	400.0	125.8	3.781E 12
400.0	800.0	128.5	7.098E 12

Table A24. Band level analyses at 18:30, 30 June, 1982.

Q9B11DB112, BASE CAMP 500 M FROM EDGE, 1830 30 JUNE 82

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
10.0	500.0	82.8	1.895E 8
100.0	500.0	82.2	1.670E 8
200.0	500.0	80.5	1.113E 8
10.0	1000.0	84.7	2.945E 8
100.0	1000.0	84.3	2.721E 8
200.0	1000.0	83.4	2.164E 8
10.0	20.0	62.0	1.584E 6
20.0	40.0	63.8	2.384E 6
40.0	80.0	70.7	1.183E 7
80.0	160.0	75.8	3.760E 7
160.0	320.0	79.0	7.879E 7
320.0	640.0	79.7	9.321E 7
100.0	200.0	77.5	5.565E 7
200.0	400.0	79.3	8.472E 7
400.0	800.0	79.6	9.179E 7

Q9B13DH112, BASE CAMP 500 M FROM EDGE, 1830 30 JUNE 82

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
80.0	4000.0	90.7	1.181E 9
800.0	4000.0	90.0	1.006E 9
1600.0	4000.0	88.6	7.281E 8
80.0	160.0	73.1	2.055E 7
160.0	320.0	75.1	3.234E 7
320.0	640.0	79.3	8.535E 7
640.0	1280.0	83.2	2.081E 8
1280.0	2560.0	86.1	4.047E 8
800.0	1600.0	84.4	2.781E 8
1600.0	3200.0	86.8	4.816E 8

Q9B15DH112, BASE CAMP 500 M FROM EDGE, 1830 30 JUNE 82

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
320.0	16000.0	91.3	1.341E 9
3200.0	16000.0	87.2	5.303E 8
6400.0	16000.0	71.2	1.326E 7
320.0	640.0	77.5	5.612E 7
640.0	1280.0	83.1	2.060E 8
1280.0	2560.0	85.9	3.868E 8
2560.0	5120.0	88.1	6.430E 8
5120.0	10240.0	76.6	4.588E 7
3200.0	6400.0	87.1	5.171E 8
6400.0	12800.0	70.7	1.171E 7

Table A25. **Band level analyses at 16:21, 30 June, 1982.**

Q9A11DB101, AMBIENT AT ICE EDGE, 1621, 30 JUNE 82

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
10.0	500.0	92.2	1.644E 9
100.0	500.0	91.9	1.542E 9
200.0	500.0	91.0	1.248E 9
10.0	1000.0	94.4	2.764E 9
100.0	1000.0	94.3	2.662E 9
200.0	1000.0	93.7	2.368E 9
10.0	20.0	68.3	6.686E 6
20.0	40.0	72.1	1.617E 7
40.0	80.0	77.0	4.985E 7
80.0	160.0	83.4	2.180E 8
160.0	320.0	89.2	8.368E 8
320.0	640.0	91.0	1.258E 9
100.0	200.0	84.7	2.937E 8
200.0	400.0	90.3	1.077E 9
400.0	800.0	90.5	1.133E 9

Q9A13DH101, AMBIENT AT ICE EDGE, 1621, 30 JUNE 82

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
80.0	4000.0	101.4	1.375E 10
800.0	4000.0	99.9	9.793E 9
1600.0	4000.0	99.0	7.960E 9
80.0	160.0	78.1	6.507E 7
160.0	320.0	94.4	2.760E 9
320.0	640.0	89.5	8.996E 8
640.0	1280.0	90.0	1.006E 9
1280.0	2560.0	97.2	5.199E 9
800.0	1600.0	92.6	1.833E 9
1600.0	3200.0	97.5	5.659E 9

Q9A15DH101, AMBIENT AT ICE EDGE, 1621, 30 JUNE 82

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
320.0	16000.0	105.4	3.497E 10
3200.0	16000.0	102.3	1.703E 10
6400.0	16000.0	99.0	7.881E 9
320.0	640.0	86.2	4.213E 8
640.0	1280.0	91.0	1.266E 9
1280.0	2560.0	100.6	1.157E 10
2560.0	5120.0	100.1	1.033E 10
5120.0	10240.0	99.3	8.471E 9
3200.0	6400.0	99.6	9.147E 9
6400.0	12800.0	97.5	5.615E 9

Table A26. **Band level analyses at 17:49 30 June, 1982.**

Q9B11DB015, 2300 M FROM ICE EDGE, 1749, 30 JUNE 82

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
10.0	500.0	93.1	2.034E 9
100.0	500.0	92.7	1.862E 9
200.0	500.0	87.2	5.271E 8
10.0	1000.0	94.1	2.593E 9
100.0	1000.0	93.8	2.421E 9
200.0	1000.0	90.4	1.086E 9
10.0	20.0	61.0	1.245E 6
20.0	40.0	66.7	4.640E 6
40.0	80.0	79.3	8.506E 7
80.0	160.0	89.8	9.581E 8
160.0	320.0	88.6	7.265E 8
320.0	640.0	86.0	3.990E 8
100.0	200.0	91.3	1.335E 9
200.0	400.0	86.4	4.402E 8
400.0	800.0	86.0	3.977E 8

Q9B13DH015, 2300 M FROM ICE EDGE, 1749, 30 JUNE 82

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
80.0	4000.0	93.8	2.385E 9
800.0	4000.0	92.0	1.573E 9
1600.0	4000.0	89.7	9.326E 8
80.0	160.0	83.6	2.297E 8
160.0	320.0	83.5	2.248E 8
320.0	640.0	82.9	1.965E 8
640.0	1280.0	88.0	6.324E 8
1280.0	2560.0	87.6	5.698E 8
800.0	1600.0	88.1	6.407E 8
1600.0	3200.0	87.9	6.191E 8

Q9B15DH015, 2300 M FROM ICE EDGE, 1749, 30 JUNE 82

FREQUENCY RANGE FROM (HZ)	TO	BAND LEVEL DB RE 1UPA	UPA**2
320.0	16000.0	93.7	2.343E 9
3200.0	16000.0	89.2	8.291E 8
6400.0	16000.0	78.6	7.229E 7
320.0	640.0	86.4	4.386E 8
640.0	1280.0	86.2	4.157E 8
1280.0	2560.0	86.8	4.770E 8
2560.0	5120.0	88.8	7.639E 8
5120.0	10240.0	83.8	2.373E 8
3200.0	6400.0	88.8	7.569E 8
6400.0	12800.0	78.3	6.776E 7

Table A27. Band level analyses at 23:36, 30 June, 1982.

Q9B11DB410, 10 NM FROM ICE EDGE, 2336, 30 JUNE 82

FREQUENCY RANGE		BAND LEVEL	
FROM	TO	DB RE	
(HZ)		1UPA	UPA**2
10.0	500.0	74.5	2.848E 7
100.0	500.0	73.3	2.159E 7
200.0	500.0	71.5	1.402E 7
10.0	1000.0	77.5	5.633E 7
100.0	1000.0	76.9	4.944E 7
200.0	1000.0	76.2	4.187E 7
10.0	20.0	59.6	9.033E 5
20.0	40.0	58.4	6.961E 5
40.0	80.0	65.3	3.416E 6
80.0	160.0	68.2	6.555E 6
160.0	320.0	69.9	9.686E 6
320.0	640.0	71.1	1.280E 7
100.0	200.0	68.8	7.564E 6
200.0	400.0	70.0	1.004E 7
400.0	800.0	71.7	1.473E 7

Q9B13DH410, 10 NM FROM ICE EDGE, 2336, 30 JUNE 82

FREQUENCY RANGE		BAND LEVEL	
FROM	TO	DB RE	
(HZ)		1UPA	UPA**2
80.0	4000.0	83.5	2.248E 8
800.0	4000.0	83.0	2.013E 8
1600.0	4000.0	81.1	1.294E 8
80.0	160.0	66.9	4.855E 6
160.0	320.0	66.2	4.210E 6
320.0	640.0	69.3	8.546E 6
640.0	1280.0	76.5	4.450E 7
1280.0	2560.0	79.4	8.722E 7
800.0	1600.0	78.6	7.189E 7
1600.0	3200.0	79.3	8.529E 7

Q9B15DH410, 10 NM FROM ICE EDGE, 2336, 30 JUNE 82

FREQUENCY RANGE		BAND LEVEL	
FROM	TO	DB RE	
(HZ)		1UPA	UPA**2
320.0	16000.0	84.2	2.646E 8
3200.0	16000.0	79.9	9.663E 7
6400.0	16000.0	69.7	9.287E 6
320.0	640.0	68.7	7.415E 6
640.0	1280.0	74.3	2.715E 7
1280.0	2560.0	79.7	9.408E 7
2560.0	5120.0	80.8	1.206E 8
5120.0	10240.0	70.6	1.142E 7
3200.0	6400.0	79.4	8.734E 7
6400.0	12800.0	68.8	7.531E 6

APPENDIX B

INDEX TO RECOGNIZED CALL TYPES

Call Type	Appendix Page(s)
1) tonal constant	100
2) tonal stepped	100
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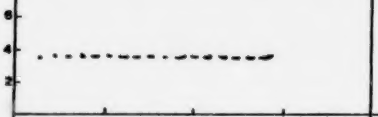
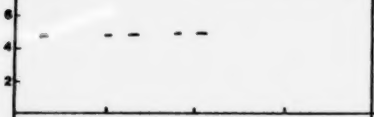
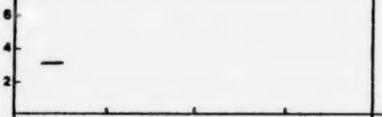
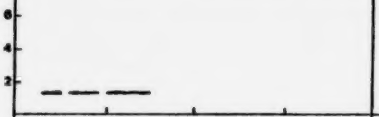
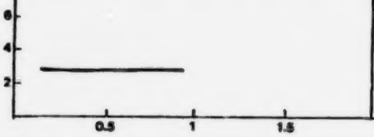
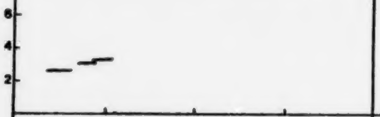
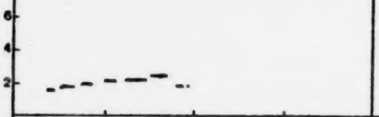
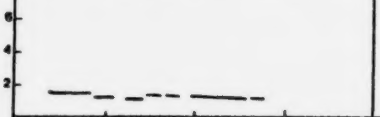
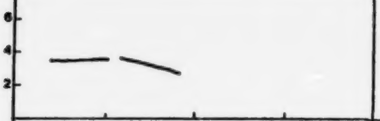
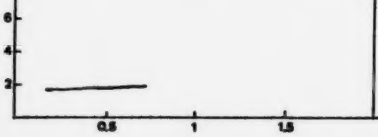
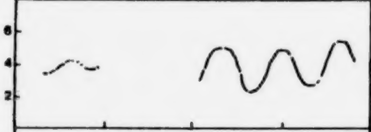
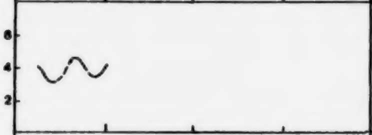
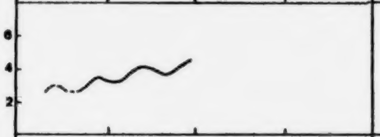
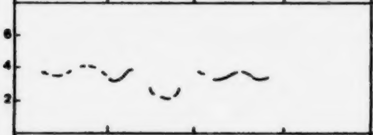
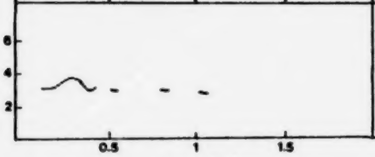
Appendix B. Recognized call types of narwhals and belugas recorded at the Admiralty Inlet ice edge during 27-30 June, 1982. The maximum and minimum frequency and duration of calls are shown.

Call type (tonal constant)	Designation	Frequency range (kHz)	Duration (s)
	tonal constant (t.c.1) dashed series	1.6-8.0	0.5-2.2
	(t.c.2) morse code	3.0-4.8	0.3-0.9
	(t.c.3) short	1.0-7.5	0.1-0.4
	(t.c.4) broken	1.0-9.0	0.5-1.1
	(t.c.5) long	1.5-6.0	0.5-1.2

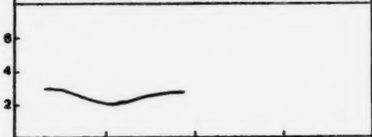
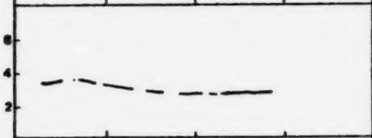
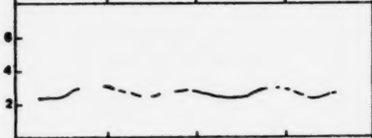
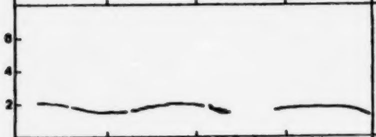
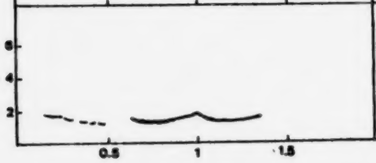
Appendix B. Continued.

Call type (tonal stepped or shifting)	Designation	Frequency range (kHz)	Duration (s)
	tonal stepped (t.s.1) 3-part up	0.7-3.8	0.3-0.5
	(t.s.2) multi-part up	1.0-5.5	0.7-1.0
	(t.s.3) falling	3.4-1.0	1.3-1.6
	(t.s.4) falling	3.5-1.0	0.5-0.8
	(t.s.5) rising	1.6-1.9	0.6

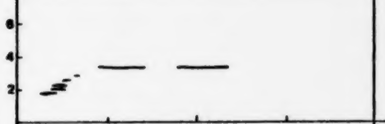
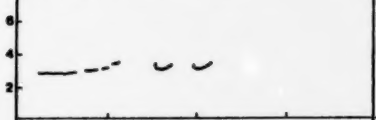
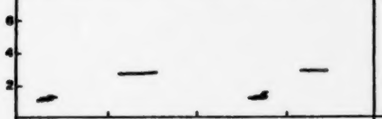
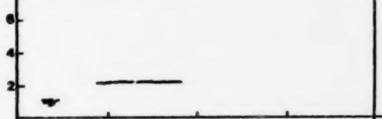
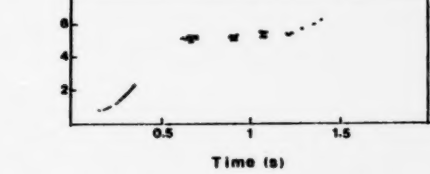
Appendix B. Continued.

Call type (tonal undulating rapid)	Designation	Frequency range (kHz)	Duration (s)
	tonal undulating rapid (t.u.r.1) up-down	3.0-8.2	0.4-0.9
	(t.u.r.2) down-up	3.0-6.2	0.3-1.7
	(t.u.r.3) rising	3-5	0.8
	(t.u.r.4) irregular	2-2.5	0.6
	(t.u.r.5) irregular/hybrid	2.5-4.0	0.4-1.0

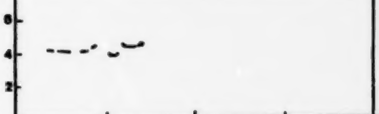
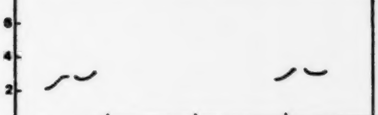
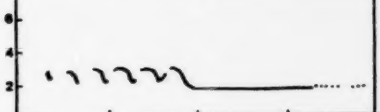
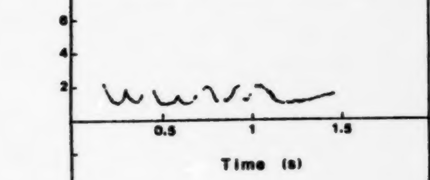
Appendix B. Continued.

Call type (tonal undulating long)	Designation	Frequency range (kHz)	Duration (s)
	tonal undulating long (t.u.l.1)	2.4-8.6	0.6-1.1
	(t.u.l.2) broken	3.4-8.0	0.6-1.3
	(t.u.l.3) regular	2.0-3.5	2.3-2.8
	(t.u.l.4) irregular with yelp	1-2	2.0
	(t.u.l.5) irregular	1-2	1.3

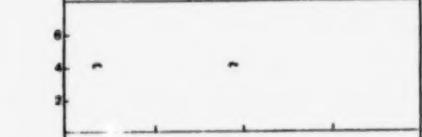
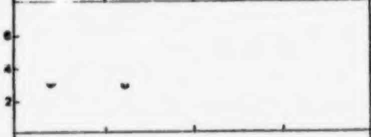
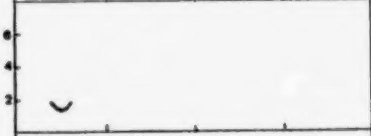
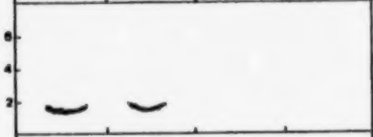
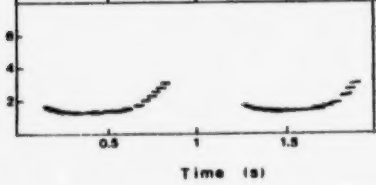
Appendix B. Continued.

Call type (tonal irregular)	Designation	Frequency range (kHz)	Duration (s)
	tonal irregular (t.i.1)	1.7-3.4	1.1
	(t.i.2)	2.7-3.5	1.0
	(t.i.3) creaking wheel series	1.0-2.8	0.5-0.7
	(t.i.4)	0.7-2.0	0.8
	(t.i.5)	0.8-6.2	1.3

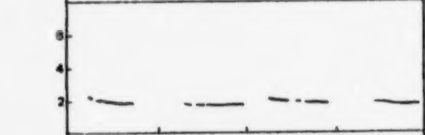
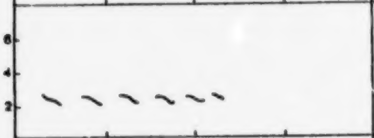
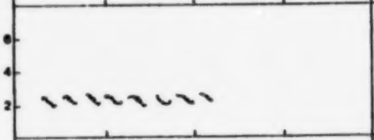
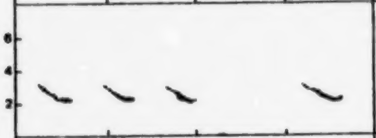
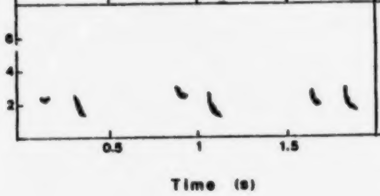
Appendix B. Continued.

Call type (tonal irregular)	Designation	Frequency range (kHz)	Duration (s)
	tonal irregular (t.i.6)	3.5-4.3	0.6
	(t.i.7)	2.0-3.0	0.3
	(t.i.8)	1.6-3.0	1.8
	(c.i.9)	1.5-2.0	1.3

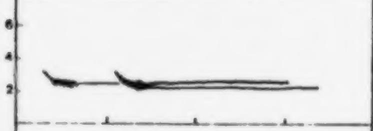
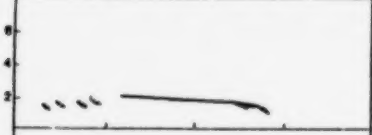
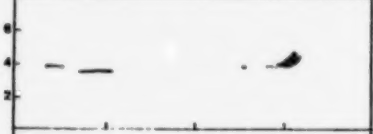
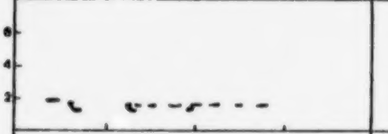
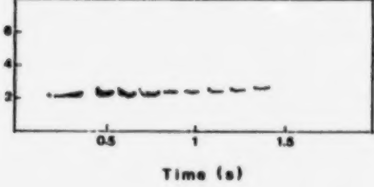
Appendix B. Continued.

Call type (sweep frequency)	Designation and aural quality	Frequency range (kHz)	Duration (s)
	sweep frequency (s.f.1)	2.5-2.8	0.05
	(s.f.2)	4.2-4.3	0.05
	(s.f.3) chirps	2.1-6.5	0.1-0.2
	(s.f.4) short yelps	1.0-1.9	0.2-0.4
	(s.f.5) long yelps	1.0-3.0	0.5-0.7

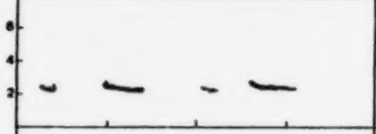
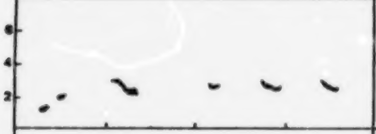
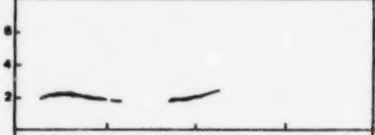
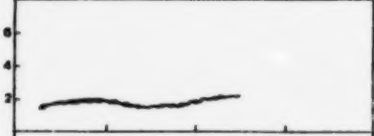
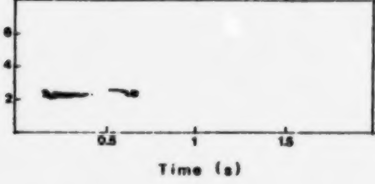
Appendix B. Continued.

Call type (sweep frequency)	Designation and aural quality	Frequency range (kHz)	Duration (s)
	sweep frequency (s.f.6) sequential, long-sweep whistles	2.5-1.5	2.5-3.1
	(s.f.7) sequential, short-sweep whistles	2.5-2.0	1.0
	(s.f.8) sequential, short-sweep, buzzy whistles	2.5-1.5	1.1
	(s.f.9) sequential yelps in series of 3-5	3.5-2.2	0.9-1.9
	(s.f.10) sequential accented yelps	3.0-1.5	1.4-1.8

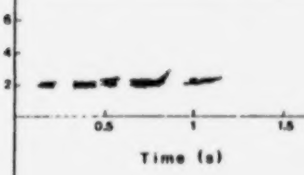
Appendix B. Continued.

Call type (sweep frequency)	Designation and aural quality	Frequency range (kHz)	Duration (s)
	sweep frequency (s.f. hybrid) paired yelp whistles	3.4-2.0	1.6
	(s.f. hybrid) accented whistle	1.3-2.0	1.3
	(s.f. hybrid) whistle chirp	3.6-4.6	1.4
	(s.f. hybrid) sequential inflected whistles	1.0-1.6	1.3
	(s.f. hybrid) chirp-whistle transform	2.0.2.5	1.3

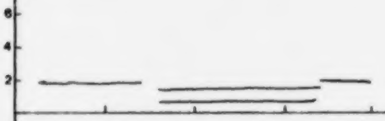
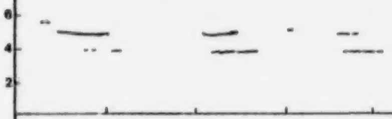
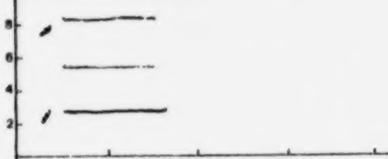
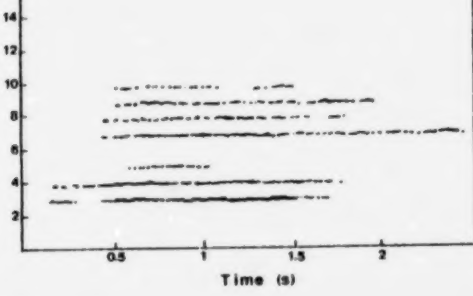
Appendix B. Continued.

Call type (sweep frequency)	Designation and aural quality	Frequency range (kHz)	Duration (s)
	sweep frequency (s.f.11) sequential accented yelps	2.7-2.0	1.4-2.0
	(s.f.12) sequential irregular yelps	0.5-1.4	1.2
	(s.f.13) modulated broken yelp	1.6-2.5	1.0
	(s.f.14) modulated yelp	1.5-2.2	1.1
	(s.f.15) whistle	2.0-2.4	0.6

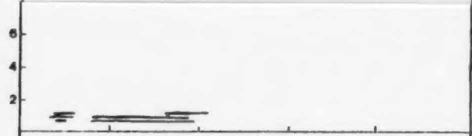
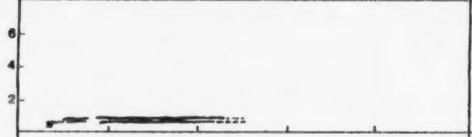
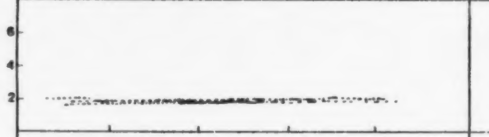
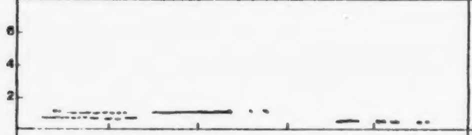
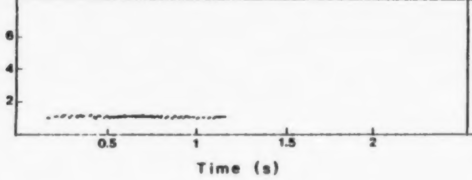
Appendix B. Continued.

Call type (sweep frequency)	Designation and aural quality	Frequency range (kHz)	Duration (s)
	sweep frequency (s.f. hybrid) melodious trill	0.9-3.0	1.1

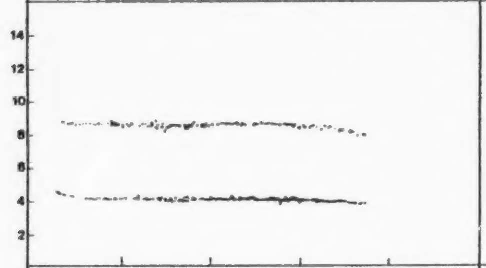
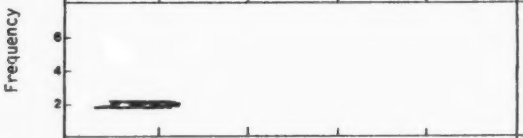
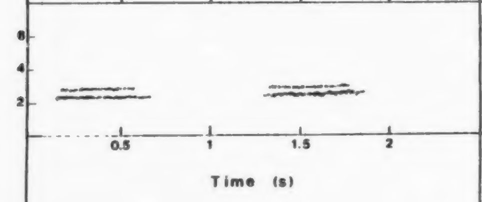
Appendix B. Continued.

Call type (complex)	Designation and aural quality	Frequency range (kHz)	Duration (s)
	complex (c.1)	0.6-2.0	1.9
	(c.2) broken screech	3.7-5.0	1.9
	(c.3) harmonic scream	2.0-8.2	0.7-1.0
	(c.4) multi-harmonic, high-pitched scream	3.0-9.0	2.4

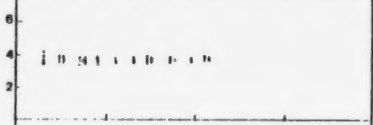
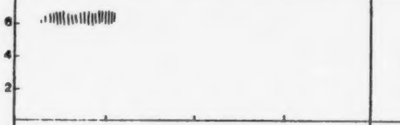
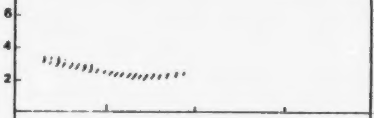
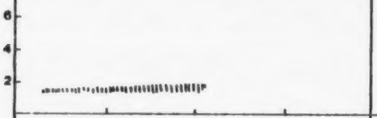
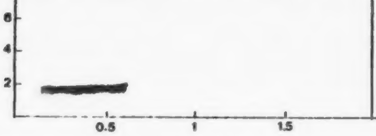
Appendix B. Continued.

Call type (complex)	Designation and aural quality	Frequency range (kHz)	Duration (s)
	complex (c.5)	1.5-3.6	0.5-2.0
	(c.6)	0.5-0.8	1.2
	(c.7)	1.6-2.0	2.0
	(c.8)	0.4-1.0	1.5-2.2
	(c.9)	0.9-1.1	1.0

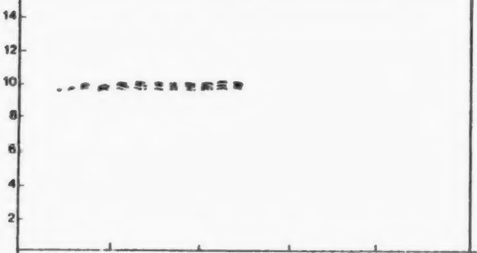
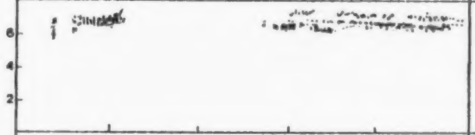
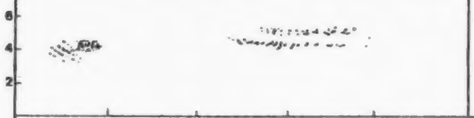
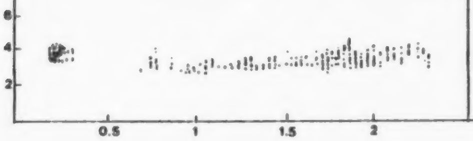
Appendix B. Continued.

Call type (complex)	Designation and aural quality	Frequency range (kHz)	Duration (s)
	complex (c.10) scream	4.2-8.5	1.75
	(c.11) blare	1.8-2.1	0.5
	(c.12) police whistle	2.1-3.0	1.3

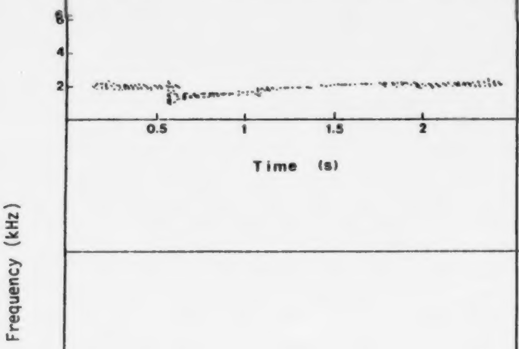
Appendix B. Continued.

Call type (pulsive)	Designation and aural quality	Frequency range (kHz)	Duration (s)
	pulsive (p.1) chips	3.7-4.2	1.0
	(p.2) insect-like buzz	6.8-7.6	0.5
	(p.3) descending rattle	2.0-3.4	0.8
	(p.4) rapid cricket	1.2-1.7	0.9
	(p.5) rasping croak	1.2-1.9	0.5

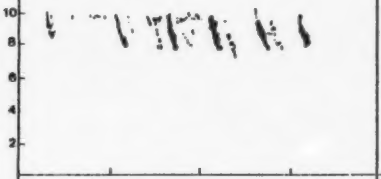
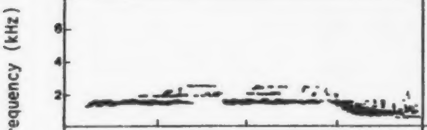
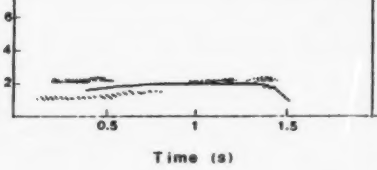
Appendix B. Continued.

Call type (pulsive)	Designation and aural quality	Frequency range (kHz)	Duration (s)
	pulsive (p.6) high frequency buzzes	9.5-10	1.1-1.3
	(p.7) harsh buzz, high frequency	6-8	2.4-3.2
	(p.8) harsh buzz, mid frequency	3.0-5.5	1.8-1.9
	(p.9) ratchet	3.0-5.0	2.1-2.4

Appendix B. Continued.

Call type (pulsive)	Designation and aural quality	Frequency range (kHz)	Duration (s)
	(p.10)	1.2-3.5	2.0-2.5

Appendix B. Continued.

Call type (miscellaneous)	Designation and aural quality	Frequency range (kHz)	Duration (s)
	miscellaneous (m. 1 var.)	8-10	1.1-1.5
	(m.2)	0.5-2.5	1.9
	(m.3)	1.0-2.5	1.5

Section 3

Report of 1983 Study

RESPONSES OF NARWHALS (*Monodon monoceros*) AND BELUGAS (*Delphinapterus leucas*) TO ICE-BREAKING SHIPS IN LANCASTER SOUND - 1983

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November 1984

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INTRODUCTION

Background

In recent years, several projects have been proposed to ship nonrenewable resources from the Canadian Arctic. The economics of these projects are improved if the length of the annual shipping season can be increased through the use of ice-breaking vessels. These proposals have raised concerns about the potential effect of noise and disturbance from ice-breaking ships on arctic marine mammals, particularly whales. Assessment of the validity of these concerns is difficult in the absence of experiments with full-size ships in the arctic. Thus, the plans by Canarctic Shipping Ltd. to increase the length of the shipping season by breaking ice to the Nanisivik mine in Admiralty Inlet provided an unique opportunity to observe the responses of whales to ice-breaking ships.

The first experiment was conducted along the ice edge across Admiralty Inlet in late June 1982. The study in 1982 was organized quickly in response to fears voiced by the hunters of Arctic Bay that the ice-breaking activities by the ore carrier MV *Arctic* might displace narwhals and interfere with hunting activities. The study in 1982 was a small prototype effort organized with less than two weeks notice between project approval and the arrival of the MV *Arctic* at the Admiralty Inlet ice edge. However, the study in 1982 clearly showed that belugas and narwhals reacted strongly to the approaching ship. Strong escape reactions began when the MV *Arctic* was 35 km away and the belugas completely vacated the Admiralty Inlet ice edge. Whales first returned to the ice edge about 30 hours after the ship reached the edge and began ice-breaking. Distribution and behaviour patterns returned to normal about 42 hours after the ship arrived (Finley et al. 1983).

Studies in 1983

In light of the results in 1982 and the general concern about shipping, a more comprehensive program was planned for the spring of 1983. The program was based on the passage of the MV *Arctic* and the icebreaker CCGS *John A. MacDonald* into Admiralty Inlet in June 1983. The Northern Affairs Program of the Department of Indian Affairs and Northern Development took the lead in funding and managing the 1983 study. Additional financial and/or logistical support was provided by Canadian Coast Guard, Canarctic Shipping Ltd., Arctic Pilot Project, Dome Petroleum Ltd., Gulf Canada Resources Inc., Consolidex-Magnorth-Oakwood joint venture and Polar Continental Shelf Project.

Three interrelated studies were conducted in 1983. The first component consisted of a series of noise trials by the icebreaker CCGS John A. MacDonald at the underwater sound range of Department of National Defense (DND) in Halifax Basin. The tests were designed to determine source noise levels of the MacDonald under various conditions of propeller loading in ice-free waters. These tests were conducted by DND and Canadian Coast Guard and the results will be reported elsewhere.

The second component of the 1983 program consisted of a ship-based study of underwater sound physics. This component measured the noise levels and characteristics of the John A. MacDonald under various ice-induced conditions of propeller loading in Baffin Bay and Lancaster Sound. Sound transmission losses in various water depths and ice conditions were also measured. These tests were conducted in cooperation with two Danish acousticians who participated through funding from the Greenland Fisheries Investigations Department of the Government of Denmark. The results of this component of the program are reported elsewhere by Greene (1984) and Thiele (1984).

The third component of the 1983 program is the subject of the present report. It deals with the behaviour and responses of narwhals and beluga whales to the MV Arctic and the CCGS John A. MacDonald.

General Approach in 1983

In 1982, we were unable to adequately document the normal behaviour patterns of belugas and narwhals before the MV Arctic arrived. Due to the lack of an aircraft dedicated to the study, it was not possible to completely document the distributional responses of the whales. In addition, the study in 1982 documented only a single passage of a single ship and could, therefore, provide no information on potential habituation to shipping. The study in 1983 was designed to provide information on all of the above questions as well as to verify that the responses observed in 1982 were typical.

The study in 1983 was conducted along the fast ice edge across Lancaster Sound to the east of Admiralty Inlet. (In 1982, the ice edge across Lancaster Sound had been west of Admiralty Inlet.) The planned general approach involved a seven day pre-disturbance period to document undisturbed behaviour; a disturbance period lasting several days; and a post-disturbance period. The disturbance period was to begin when the MV *Arctic* approached and entered the ice. The *Arctic* would then proceed to break through the ice to Nanisivik mine, load her cargo, and then return to the ice edge. During this period, the *John A. MacDonald* was to operate for a few hours every two days in a effort to simulate a moderate level of ice-breaking ship traffic through Lancaster Sound. This would provide data to evaluate the effects on whales of several ship passages and to assess whether the whales habituated to the traffic. The length of the post-disturbance period was to be determined by ship schedules and safe ice conditions. As events unfolded, the *Arctic* was unable to proceed to Nanisivik without the aid of the icebreaker *MacDonald*. This led to a revised study design but a series of discrete disturbances did occur (see Methods) and was evaluated (see Results).

Three basic data gathering procedures were used. (1) Frequently-repeated aerial surveys were designed to assess large-scale patterns of distribution and movement by whales. (2) Ice-based observers documented small-scale distribution and movement and the visible behaviour of the whales. (3) Underwater hydrophones provided information on natural ambient noise levels, received levels of ship noise, and whale vocalizations. The data concerning ship noise levels and whale vocalizations were then related to the behavioural and distributional data obtained by aerial and ice-based observers.

Related Studies

The study reported here was phase 2 of a three-phase study begun in 1982. The results of the 1982 study were reported in

Finley, K.J., C.R. Greene and R.A. Davis. 1983. A study of ambient noise, ship noise, and the reactions of narwhals and belugas to the MV Arctic breaking ice in Admiralty Inlet, N.W.T. - 1982. Rep. by LGL Limited, Toronto, for Canada Department of Indian Affairs and Northern Development, Ottawa. 108 p.

Phase 3 of this project consisted of a series of aerial surveys flown along the Lancaster Sound ice edge in the spring of 1984 to document the reactions of whales to the MV Arctic and CCGS Louis St. Laurent. The results of phase 3 are presented in

Miller, G.W and R.A. Davis. 1984. Distribution and movements of narwhals and beluga whales in response to ship traffic at the Lancaster Sound ice edge - 1984. Rep. by LGL Limited, King City, Ontario, for Canada Department of Indian Affairs and Northern Development, Ottawa. 34 p.

The results of all three phases of the study are integrated and presented in the overview report

Finley, K.J. and R.A. Davis. 1984. Reactions of beluga whales and narwhals to ship traffic and ice-breaking along ice edges in the eastern Canadian High Arctic: 1982-1984. An overview. Rep. by LGL Limited, King City, Ontario, for Canada Department of Indian Affairs and Northern Development, Ottawa. 42 p.

METHODS

Study Design and Area

The field study was to begin with a pre-disturbance period of duration about 7 days to document the normal patterns of distribution, abundance and behaviour of the whales. Then, following the initial entry into the ice by MV Arctic, controlled disturbance trials were to be conducted at approximately 2-day intervals to evaluate habituation by the whales (i.e. return to normal densities, distribution and behaviour). The disturbance trials depended on the availability of the CCGS John A. MacDonald. However, the unusually severe ice conditions precluded the planned experiments by making it necessary for MacDonald to escort Arctic through the fast ice to Nanisivik in Strathcona Sound. This unexpected situation necessitated a revision of the experimental design.

The first disturbance period coincided with the arrival of the Arctic on 24 June. The second disturbance period occurred on 26 June when the MacDonald arrived at the ice edge. The two ships then proceeded together westward through the fast ice. The ships generally stopped at night, providing quiet intervals between the periods of icebreaking disturbance during the day. The slow progress of the ships through the ice provided five disturbance periods during which ship noise was present at the ice edge. Overall, a total of seven disturbance periods with intervening quiet intervals were recognized during the study.

Originally, we planned to conduct observations and underwater recordings from two stations on the ice, one on either side of the ship's point of entry into the fast ice. However, this was not possible due to the configuration of the Lancaster Sound ice edge and the routing strategy of the Arctic. The ship followed the path of least resistance, close to and paralleling the winter shear zone[1] (Fig. 1). Thus, the observation sites were located on the southern corner of the Lancaster Sound ice sheet where it joined the

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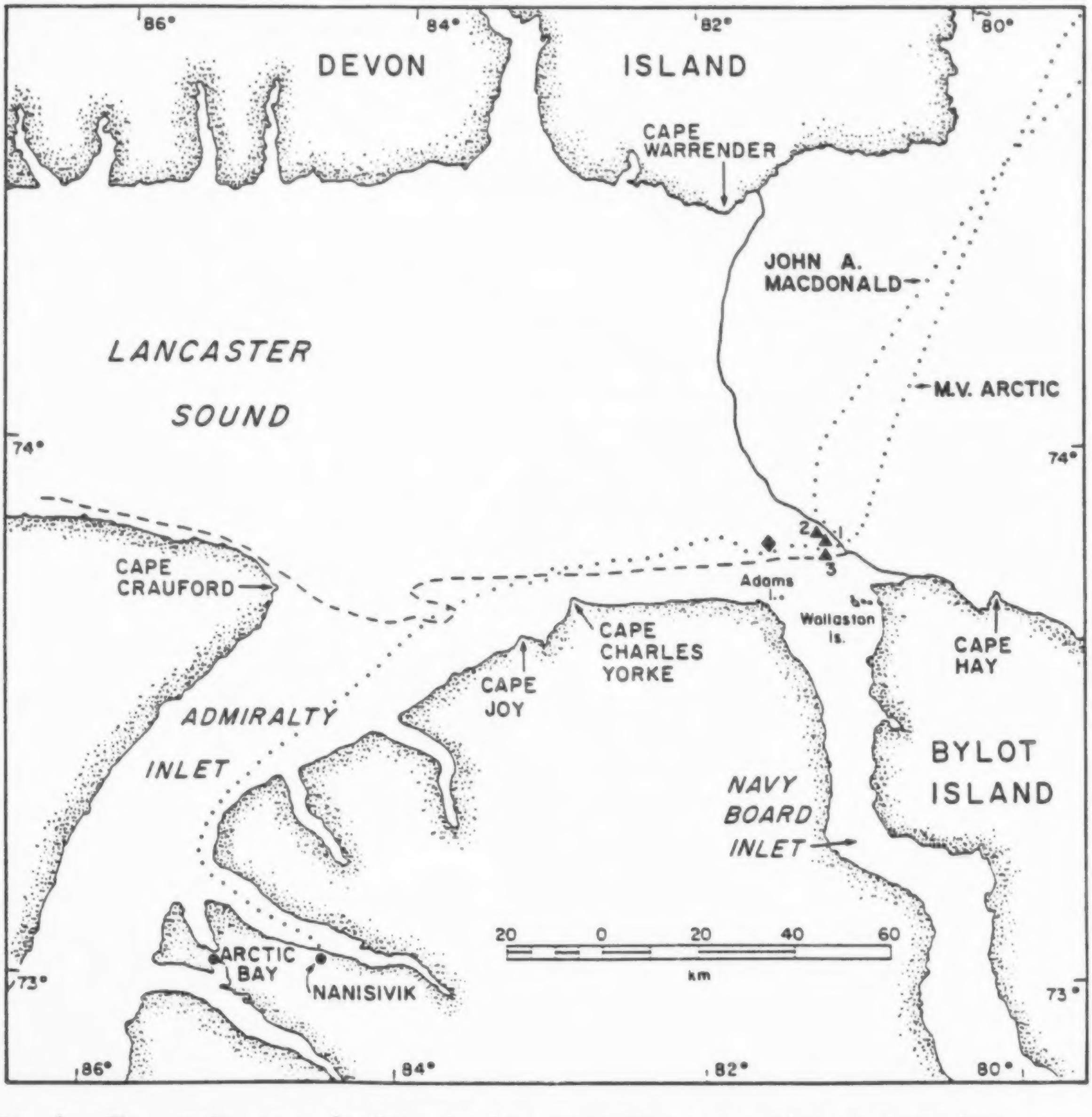
[1] The shear zone represents the winter boundary between shore-fast ice and the central core of pack ice which remains in intermitted restricted motion until late winter.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DEVON
ISLAND
CAPE WARRENDER
JOHN A. MACDONALD
M.V. ARCTIC
LANCASTER
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1
3
Adams I.
Wollaston Is.
CAPE CRAUFORD
CAPE CHARLES YORKE
CAPE JOY
CAPE HAY
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INLET
BYLOT
ISLAND
NAVY BOARD INLET
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ARCTIC BAY
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Fig. 1. The study area showing the Lancaster Sound ice edge in late June, 1983. Observation/recording stations (occupied from 19-27 June) are indicated by solid triangles. A 'satellite' recording station (occupied 24 June) is indicated by a diamond. The shear zone and the route of the ships MV Arctic and CCGS John A. MacDonald are shown as dashed and dotted lines, respectively.

east-west oriented shear zone. This 'corner' situation was not ideal for study purposes since the movements and behaviour of the whales were complicated by the junction of the ice sheets. Finally, the precariousness of working from an ice platform made safety precautions paramount while conducting the study. This was made clear on 24 June when the Arctic arrived a day earlier than anticipated during a heavy snowstorm and, without radio contact, cut into the fast ice between the ice-based camp and shore. Gaps in the sampling effort occurred when the camp was moved for safety reasons.

A post-disturbance period was planned but continued ship operations, changes in the ice configuration after 2 July and additional levels of disturbance from Inuit hunting activity prevented systematic observations. During this phase of the study we conducted observations and recordings mostly on an opportunistic basis and depended on aerial surveys for information about the distribution and numbers of whales and their responses to habitat changes (i.e. ice cracks) and additional disturbance from hunting.

Ice Conditions

Ice conditions were unusually severe in 1983; the ice edge in Lancaster Sound was located much farther east than normal, requiring the ships to penetrate much more fast ice (102 km more than in 1982) to reach the Nanisivik mine (Fig. 1). Aerial surveys encompassed this ice edge across Lancaster Sound (about 90 km), along with the adjacent Navy Board Inlet ice edge (15 km) and short segments (18 and 8 km, respectively) of the coasts of Devon and Bylot islands (Fig. 1).

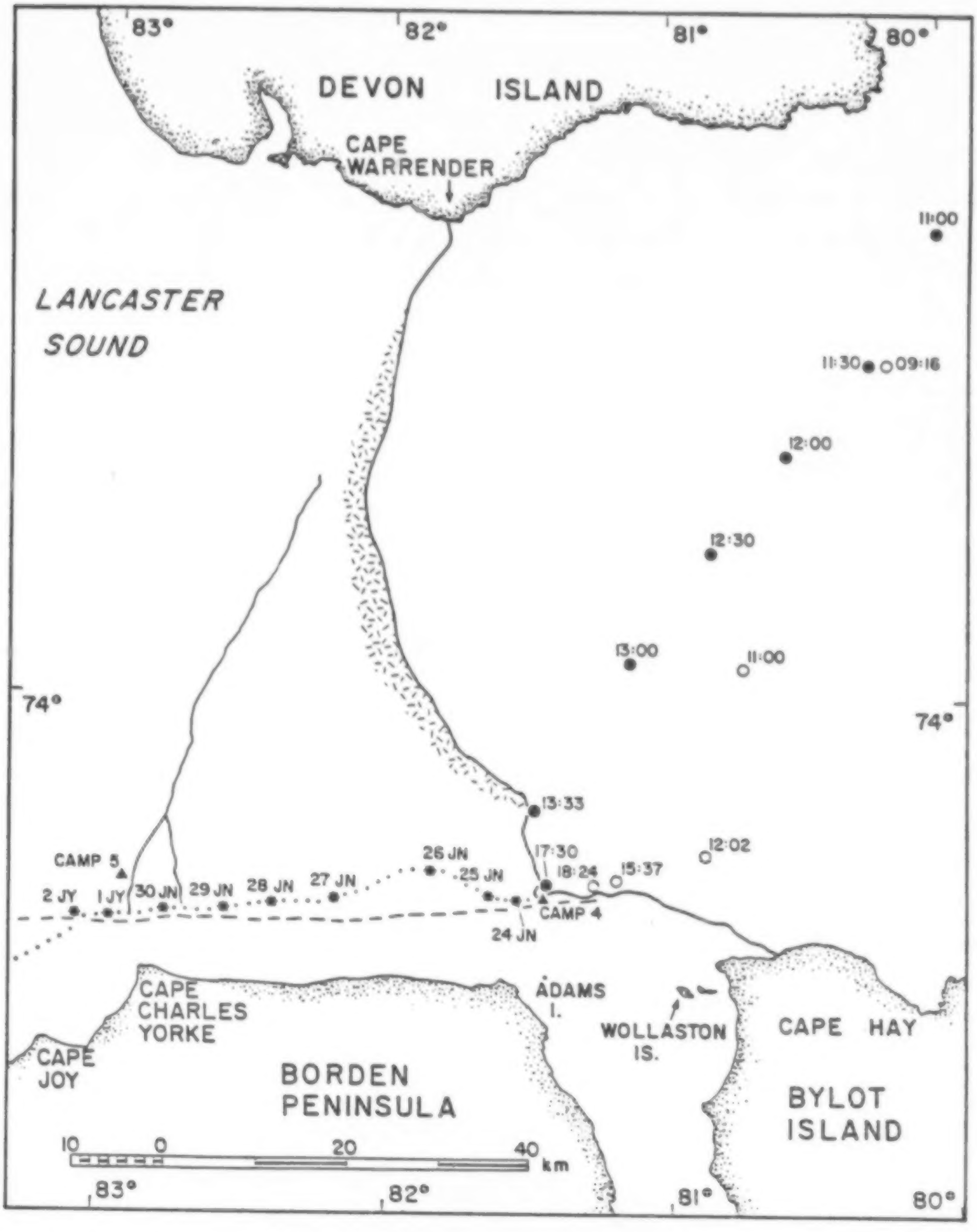
The Lancaster Sound ice edge remained intact until early July, although in some areas waves broke off pieces 1 km or more in diameter, particularly from the central portion of the edge. The central portion of the ice edge consisted of a band (up to 5 km in width) of thinner fast ice that became perforated by melt holes in early July. East of the ice edge Lancaster Sound was largely ice free during the study. However, during the first four aerial surveys (17-21 June), the northern portion of the ice edge was beset by a dense band of pack ice and the coast of Devon Island was bordered by a narrow band of fast ice. This broke back to Cape Warrender on 23 June.

The fast ice in Lancaster Sound remained solid until around 18:00 on 2 July when a large sheet bordered by the ship track shifted slightly, leaving a narrow lead or crack that ran 45 km from the centre of the ice edge southwest to join the ship track off Cape Charles Yorke (Fig. 2). The observation and recording camp was re-located to the terminus of this crack on 3 July and remained there until 8 July when the ice became more unstable. After this, poor weather and extensive fog prevented further detailed observations on the extent of ice break-up in Lancaster Sound which did not take place until after mid July.

Aerial Surveys

Aerial surveys were conducted from a Bell 206B helicopter flown at altitudes ranging from 152-305 m (500-1,000 ft), depending on weather and visibility. Average ground speed was 185 km/h (100 kt). The primary observer was seated in the left front seat of the helicopter and a second observer was on the right side of the aircraft. Surveys were flown approximately 400 m off the ice edge. Later in the field season, aerial surveys also covered the ship track and major cracks that developed in the fast ice. Aerial coverage of the ice edge normally extended from Cape Hay on northwest Bylot Island to the Cunningham West glacier about 18 km east of Cape Warrender on Devon Island (Fig. 3). Thus the entire survey covered about 105 km of ice-edge habitat and 26 km of coastal habitat. Portions of the normal survey were sometimes not completed because of poor visibility or large amounts of pack ice blown against the ice edge. The dates of the 18 aerial surveys and other sampling events are shown in Figure 4.

Numbers of marine mammals, their behaviour (including activity, direction of movement and proximity to the ice edge), and sex and age information were recorded onto audio tape. Times of sightings of marine mammals and major ice features were noted and later used to estimate positions of animals. For mapping purposes, the ice edge was divided into 5 segments (Fig. 3). The southernmost segment extended from Cape Hay westward along the Navy Board Inlet ice edge to the northern edge of the shear zone. The next segment, which encompassed the disturbance zone where the ships entered the ice, extended from the shear zone north along a section of smooth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DEVON ISLAND
CAPE WARRENDER
LANCASTER SOUND
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74°
13:33
17:30
18:24
15:37
12:02
CAMP 5
26 JN
25 JN
27 JN
28 JN
29 JN
30 JN
1 JY
2 JY
CAMP 4
24 JN
ADAMS I.
WOLLASTON IS.
CAPE HAY
CAPE CHARLES YORKE
CAPE JOY
BORDEN PENINSULA
BYLOT ISLAND
10
0
20
40
km
83°
82°
81°
80°

Fig. 2. The study area showing the Lancaster Sound ice edge in early July, the ship routes, and a major ice crack that formed on 2 July. Positions of ships during their open-water approach to the ice edge are indicated by open circles (MV *Arctic*, 24 June) and solid circles (CCGS *John A. MacDonald*, 26 June). The farthest daily positions during ice breaking are indicated by asterisks. The positions of observation/recording stations 4 (in the ship bight) and 5 (at the southern end of the ice crack) are indicated by triangles. The shear zone and the route of the ships are shown as dashed and dotted lines, respectively.

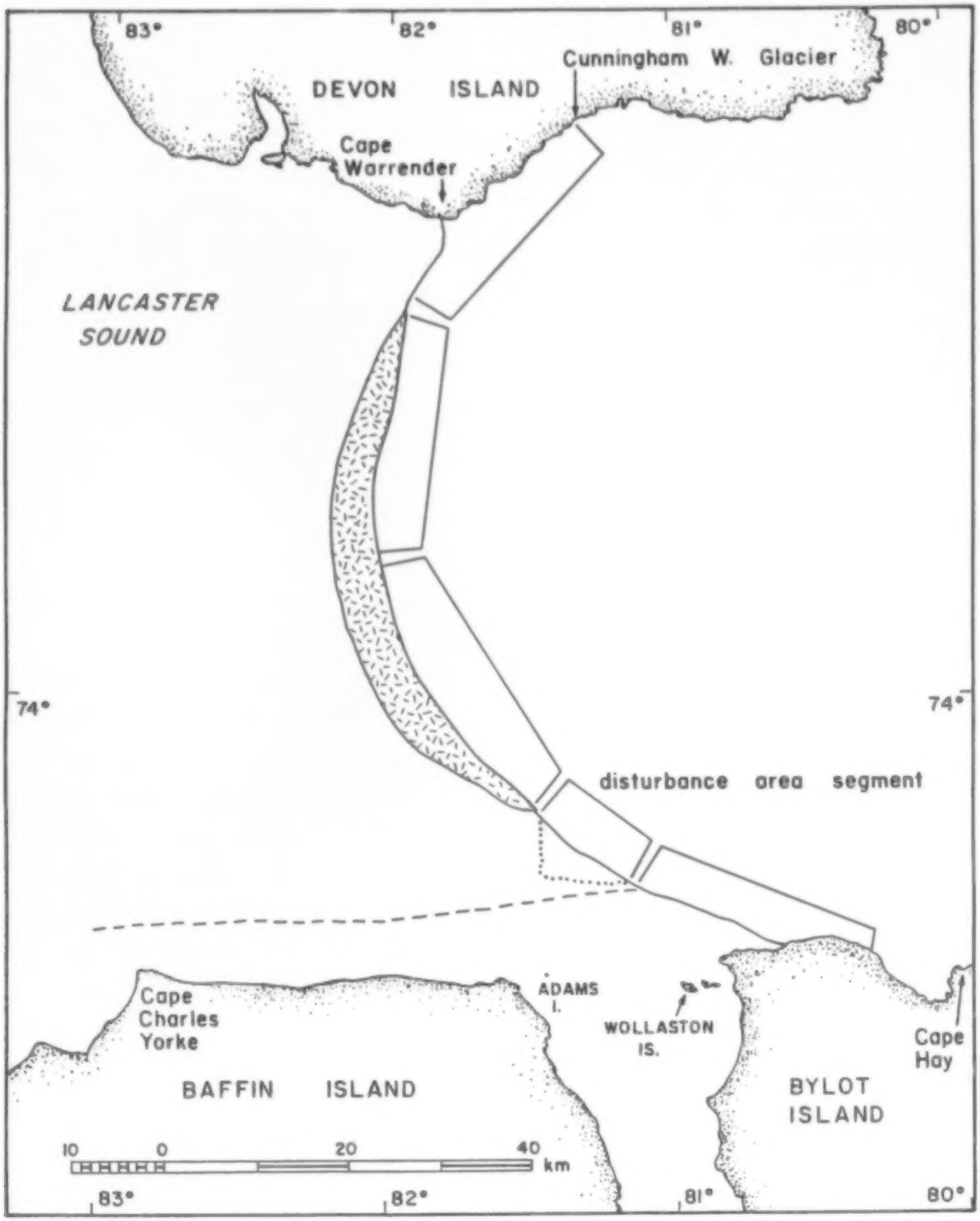

83°
82°
81°
80°
Cunningham W. Glacier
DEVON ISLAND
Cape Warrender
LANCASTER SOUND
74°
74°
disturbance area segment
Cape Charles Yorke
ADAMS I.
WOLLASTON IS.
Cape Hay
BAFFIN ISLAND
BYLOT ISLAND
10
0
20
40
km
83°
82°
81°
80°

Fig. 3. Schematic representation of the five segments of the ice edge recognized during aerial surveys that were used to describe the distribution of whales in 1983. The central portion of the ice edge consists of a narrow margin of thinner ice represented by stippling. The disturbance area segment encompassed the ice edge between the shear zone and the thin ice and, after 27 June, the ship-induced bight (dotted line).

ice to a margin of thin, perforated ice. The central portion of the edge was divided into two segments of equal length. The fifth segment extended from the northern end of the thin ice past Cape Warrender along the south coast of Devon Island. The coastal shelf of fast ice broke back to Cape Warrender on 23 June and subsequent surveys were conducted along the Devon coastline to the same end point (opposite Cunningham West Glacier) as in earlier surveys.

Principal directions of movement for narwhals and belugas are indicated on the aerial survey maps when 75% or more of the whales whose direction was noted were moving in the same direction in a particular segment. Movements are only indicated for samples of 20 or more whales in a segment. Samples from adjoining segments were sometimes combined to meet the latter criteria if the general direction of movement was the same in the adjoining segments.

Ice-based Observations

Observations were conducted from the ice edge throughout the pre-disturbance and disturbance phases of the study. Continuous observations were attempted but unstable ice and frequent camp moves necessitated some interruptions in the schedule (Fig. 4). Ice-edge observers, sometimes using binoculars, recorded species and numbers of marine mammals, their activity, direction and speed of movement, distance from the ice edge, and age and sex information. Direction of movement data are plotted by hourly periods for all whales whose direction of movement was recorded during selected phases of the study. Data on the distances of whales from the ice edge are also plotted for selected phases of the study. Estimated distances from the ice edge were grouped into one of the 4 following distance categories: $\leq$10 m, 11-50 m, 51-100 m, and 100-500 m. Whales could not be reliably sighted beyond 500 m.

A scan sampling technique was also employed, particularly after 27 June when observations were conducted at a bight in the ice edge created by the passage of the ships. Whales tended to concentrate in the bight but lateral movements of whales along the edge were difficult to observe. This procedure required observers to scan the area visible to them with binoculars and to record the numbers of marine mammals of each species engaging in the

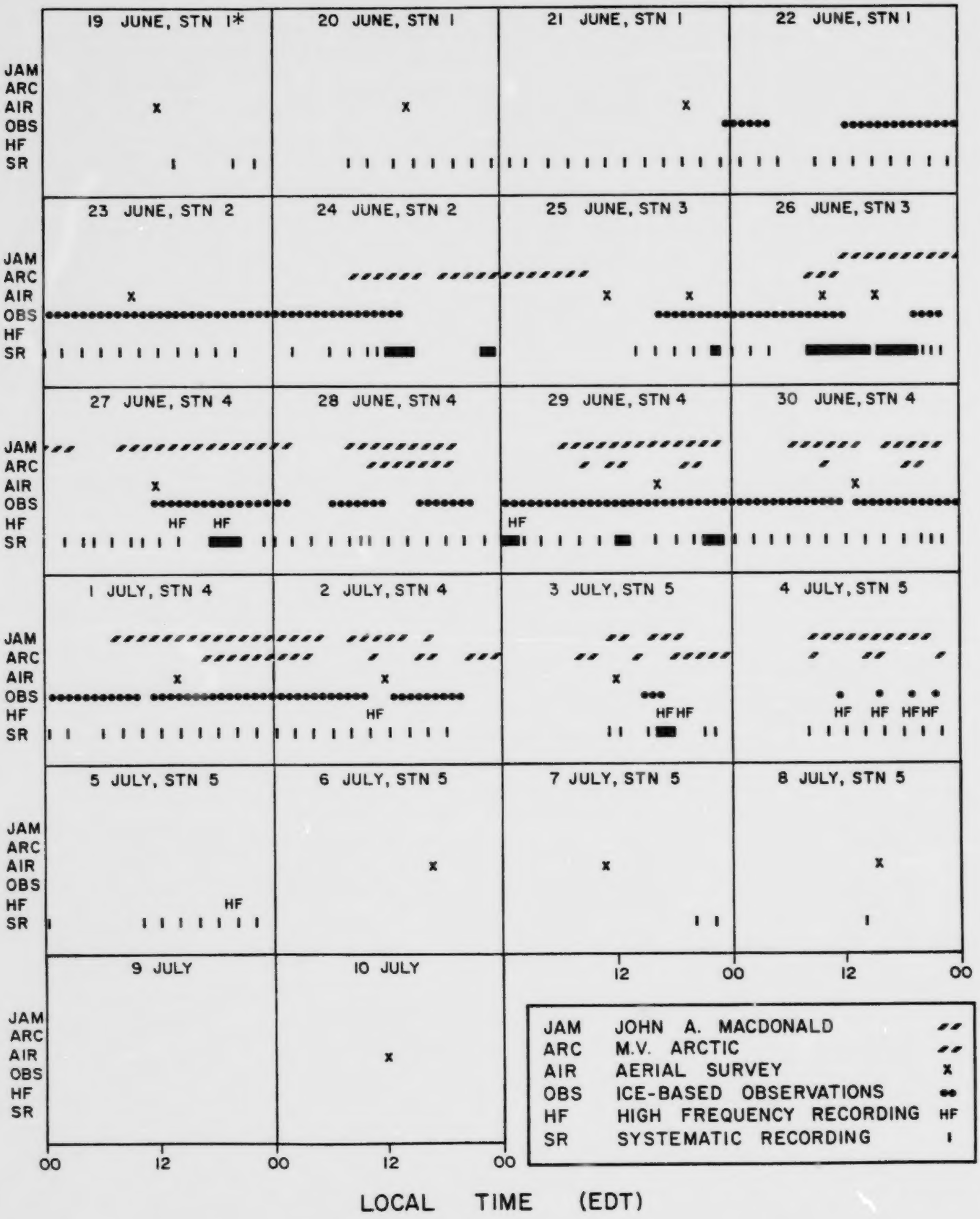


Fig. 4. Temporal distribution of sampling effort (acoustic recordings, aerial surveys and ice-based observations) and periods of ship disturbance. After 3 July the study entered an ice crack/hunter disturbance phase; ship noise became insignificant and periods of operation are not indicated. See Figures 1 and 2 for locations of observation/recording stations 1-5.

following activities: swimming (directed movement), circling or resting, interacting socially (e.g., body contact, pursuit), or diving.

Whales observed during aerial surveys and ice-based watches were classified according to the following age/sex criteria. Narwhals with tusks (and occasionally pods of adult belugas that observers thought were males) were classified as adult males. Adult narwhals and belugas that were not sexed, but that were not accompanied by immature animals, were simply designated as unaccompanied adults. Adult narwhals without tusks, and adult narwhals and belugas accompanied by immatures were classified as females. Neonates, yearlings and subadult whales were classified as immatures. Groups of whales were sometimes called a mixed group of females and immatures by observers, but the specific number of each was often not recorded although the total number in the group was noted. In this case, the whales were classified as unspecified females and immatures.

We constructed histograms based on these age/sex classifications. Males and unaccompanied adults are grouped together (but each component is identified) as are females, immatures and unspecified females and immatures (also identified). Thus, the basic distinction made is between whales that were probably males and whales that were females and immatures.

In this report we use the term 'pod' to describe a social behaviour of belugas or narwhals. Pods are clearly recognizable structural units occurring within or outside the 'herd'. Pods are cohesive units and their 'integrity' is evident by the regulating of individual spacing, body orientation and synchronous movements. 'Loss of pod integrity' is a clearly recognizable behavioural state, although it cannot be quantitatively defined without photographic work.

Underwater Recording

Sampling Protocol

Hydrophones were deployed under the ice to record the natural ambient noise levels in the water, animal calls, and noise emanating from the ships. The basic systematic recording protocol consisted of one 10-min recording session every two hours during the study. We attempted to record 12 of these sessions every day during the study but several gaps in coverage occurred when it was necessary to move the camps for safety reasons (Fig. 4). Overall, 150 10-min sessions (25 h) were obtained. In addition, we increased the frequency of the 10-min recordings to one per hour when the ships were approaching the ice edge and we recorded continuously when they had approached within 20 km of the edge. Continuous recording was also conducted opportunistically on other occasions. A total of 20 h of continuous recordings were obtained (Fig. 4).

The locations of the recording stations are shown in Figures 1 and 2. The period when each station was occupied and the water depth below each station are given in Table 1.

Table 1. Positions and periods of occupation of recording stations in Lancaster Sound, 1983.

Station #	Period Occupied	Water Depth (m)	Ice Conditions
1	19-22 June	675	Smooth first-year ice (1.7 m thick) about 1.5 km north of shear zone, 800 m from ice edge
2	23-24 June	725	Smooth first-year ice (1.7 m) about 3 km north of shear zone, 400 m from ice edge
Satellite	24 June	650	Hummocky first-year ice (2.1 m) about 1 km north of shear zone, 11 km west of ice edge
3	25-27 June	575	Rafted first-year ice (2.6 m) near shear zone, 200 m from ship track
4	27 June–2 July	600	Rafted first-year ice (>2.0 m) near shear zone, 20 m from ship track
5	3-8 July	525	Hummocky first-year ice (1.8 m) along ice crack, 1.5 km from ship track

In addition to the regular recording stations, a satellite recording station, located on the fast ice about 11 km west of the ice edge (Fig. 1) was occupied from 00:00 to 10:00 on 24 June. Recordings at this site were conducted every 2 h, synchronously with recordings at Station 2. The purpose of these recordings was to compare ambient noise levels in the ice where few animals were present with noise levels at the ice edge where animal calls dominated the ambient noise. Originally it was planned to conduct this experiment 20 km from the ice edge for a full 24 h but poor weather and rough ice prevented us from going more than 11 km from the edge. The unexpected early arrival of the Arctic contaminated the ambient noise at both stations by 10:00 and the experiment was terminated.

Recording Equipment

Instrumentation was assembled for sound recording in the frequency range from 10 to 16,000 Hz to quantify the natural background levels, animal sounds and ship sounds in the band audible to humans. Hydrophones were deployed at two depths, 3 and 20 m, so that any depth-related differences in the received sounds could be measured. We used U.S. Navy model H56 standard reference hydrophones, which are wideband (to 50 kHz) low noise hydrophones with built-in preamplifiers. We also used low noise bender hydrophones with built-in preamplifiers useful at frequencies below 2000 Hz. The hydrophones were assembled into vertical strings for suspension through holes and cracks in the ice. Each such string included a fairing to minimize the inevitable cable flutter resulting from even small currents. Each hydrophone had a postamplifier with selectable gain (in 10 dB steps) up to 60 dB. The postamplifier outputs were the inputs to the tape recorder.

Three kinds of tape recorders were used. The simplest was a Sony WM-D6 Pro-Walkman, a small but high quality two-channel cassette recorder with a servo-controlled capstan for constant tape speed. Another type was Sony's model TC-D5M two-channel cassette recorder, also with servo-controlled capstan. The most versatile recorder was the Fostex model 250, a four-channel cassette recorder with servo-controlled capstan and a tape speed twice that of the other recorders for better high frequency response. All three recorders ran on batteries, but the Fostex required a DC-to-AC inverter and an automobile storage battery.

The TC-D5M and the Fostex recorders were used at the ice edge camps. The Pro-Walkman was used at the satellite camp and at a temporary ice edge camp established after the Arctic arrived.

Analyses of Ambient and Ship Sounds

The laboratory analysis of the tape recorded sounds was based on the use of a Hewlett-Packard model 9816 computer system with an analog-to-digital converter. The A/D converter operates at speeds up to over 100,000 samples/second, converting voltages between + and - 10 into 12-bit computer words. Up to 65,000 samples can be converted and saved in succession. The system allows for on-line hard disk storage (14.5 Mbytes) and for backup on 3.5 inch diskettes.

Several programs were used to analyze the data. In addition to the program for controlling the A/D converter, we used a program for power spectral density estimation based on computing discrete Fourier transforms. The stored samples representing a given section of recording were segmented into blocks, then weighted with a window function to suppress "leakage". The segments were overlapped 50% to minimize the effective data loss from the windowing. The power spectrum was computed for each transform result, and all the resulting spectra were averaged to derive the estimated power density spectrum for the original stored samples. The sample rate, block size, and window shape determined the spectral resolution, frequency spacing, and frequency range covered in the spectrum.

Another program applied the recording system sensitivity and gain characteristics to every frequency cell computed in the spectrum, providing a result referred to a unit of sound pressure. Still another program combined spectrum levels to compute band levels for one-third octave bands and wider bands. It printed those levels and plotted the spectrum, thereby completing the power spectral density analysis for a given section of sound recording. Further details about the digital analysis procedures are given by Greene (1984).

Often, especially in the case of animal sounds that change frequency rapidly, it is desirable to see how the power density spectra change with time. Such displays are called 'spectrograms', or waterfall spectral displays. We applied a program to plot such displays (Greene 1984).

Analysis of Whale Vocalizations

All 45 hours of recorded tapes were carefully listened to and detailed notes were taken. After familiarization with the sound types, the tapes were listened to a second time and the level and type of vocal activity was subjectively gauged. Each 10-min recorded session constituted a sample unit; vocalizations were identified by species and recorded as absent or present and, if present, whether distant or in close proximity to the recording station. The predictions of absence or presence of narwhals and belugas were tested for accuracy by comparison with the independent observations of the ice-based observers (see Results). Not surprisingly, this process demonstrated that vocalizations were a reliable indication of presence or absence of each species.

Taped segments of 30 s duration were then randomly selected for spectral analyses from those 10-min sessions that had reasonable signal:noise ratios. In some sessions where ship noise predominated, it was necessary to select quieter moments when the ship shifted between a ramming and reversing mode. The selected segments were analyzed using a Spectra Color real-time spectrum analyzer operating in the frequency bandwidths of 60-6,000 Hz and 60-12,000 Hz. The frequency composition and duration of sounds were measured from the video output from the spectrum analyzer. A calibrated acetate overlay was superimposed onto a 2-s video display held in freeze frame by a specialized 5-head Hitachi VTR-7 recorder. In addition, spectographs of various call types were produced on a Kay Electric 7029 A spectrum analyzer (see Figs. 5-11).

Vocal activity was evaluated from a total of 77 30-s spectrographic segments; 24 of these came from the pre-disturbance period, 33 from the disturbance periods, and 20 from the intervening quiet periods. The results of this analysis yielded uneven results. For example, it was seldom possible to distinguish individual click series from the general 'clatter' when narwhals were present but pulsed tones tended to be discrete and distinctive, allowing enumeration. Belugas are highly gregarious and garrulous (for which they richly deserve their reputation as "sea canaries") and attempts to quantify the level of vocal activity were very difficult (imagine 100 canaries in an aviary). Overlapping signals could usually be separated on the basis of relative level and close attention to the real-time spectral display but it was often impossible to discern how many components constituted a single call. Belugas in close quarters usually produced a cacophony of sound that we did not attempt to interpret or quantify. The results of this analysis of vocal activity are presented only as a coarse approximation of their broad lexicon.

Although the social signals of narwhals and belugas fall primarily in the human audible range (primarily below 10 kHz) and within the frequency limits of our systematic recording system, some signals, particularly those used for echolocation, are known to be emitted at frequencies as high as 120 kHz by the beluga in a captive environment (Wood and Evans 1980) and up to 24 kHz by the narwhal in the wild (Watkins et al. 1971; Ford and Fisher 1975). We examined high-frequency (to 120 kHz) tapes obtained in close proximity to narwhals in an attempt to ascertain the upper frequency limits of sounds emitted by this species.

RESULTS

The basic results are presented in a chronological format starting with the pre-disturbance period before the ships arrived at the ice edge. Subsequent sections describe the arrival of the MV Arctic followed by alternating quiet intervals (ships inactive) and disturbance periods (ships active). For each of these periods, we present the available data concerning large scale distribution and movement patterns (aerial surveys), visible whale behaviour (ice-based observations), and whale vocal behaviour (hydrophones). Also presented are relevant data on ambient noise and ship noise levels. Before presenting these results, it is necessary to review briefly the vocal repertoire of belugas and narwhals at the Lancaster Sound ice edge. This information is necessary background for interpretation of whale calls recorded under various disturbance conditions.

Classification of Whale Vocalizations

Our recording stations at fixed positions on the Lancaster Sound ice edge provided ideal situations to simultaneously listen to and observe narwhals and belugas, both intermingled and apart. In 86 sessions when ice-based observations and underwater recordings were complete and synchronized, it was possible to predict from the tapes (96% accuracy - Table 2) which species was present in the immediate area and to gauge roughly its abundance and level of activity.

Table 2. Prediction of presence or absence of narwhals and/or belugas based on 86 underwater recording sessions synchronized with ice-based observations.

	Predict present		Predict absent	
	correctly	incorrectly	correctly	incorrectly
Belugas	40	2	44	0
Narwhals	43	3	38	2

In five cases, beluga (2 cases) and narwhal (3) calls were thought to be present on the tapes but the observers did not see any animals nearby, even through visibility was fair to good. However, in each of the cases the species in question had been seen in the area during the recording sessions immediately preceding or following. Incorrect predictions of absence occurred on two occasions when narwhals were present but apparently silent.

The general acoustic repertoire of narwhals and belugas was learned from those recording sessions in which we were certain that only one species was present in the area. This repertoire was compared with other recordings (J. Ford, K.J. Finley, unpubl. data) of narwhals and belugas in their summering areas where it was certain that only one species was present. Generally, we found that the majority of calls could be easily classified but with belugas we found that the repertoire was an intergraded spectrum with some call types more common than others. Examples of various call types are presented in Figures 5 to 11 and a general description of the basic categories is given below.

Narwhal

The basic vocalizations of the narwhal (Figs. 5 and 6) have been described by Watkins et al. (1971) and Ford and Fisher (1978).

Clicks.--Narrow-band pulses of constant frequency in series generated at regular and generally slow (mostly <10/s) repetition rates. Most audible energy in the frequency range 3-7 kHz (Fig. 5A, B).

Pulsed Calls (Creaks and Growls).--Rapidly pulsed emissions ranging from slower ratchet-like growls to higher-pitched creaking sounds. Pulsed tones were generated at frequencies from 500 Hz to 6.5 kHz and had a narrow-band frequency structure. Durations from 0.3 to 1.5 s (Figs. 5C, 6A, B, C).

Pure Tones (Thin Whistles).--Infrequent whistles having a narrow-band frequency content usually of continuous duration and changing pitch. Aurally they were usually distinguished from beluga tonals by their relative 'thinness' of frequency content. Primarily in the range of 500 Hz to 10 kHz and usually of short duration (<0.5 s) (Fig. 6C).

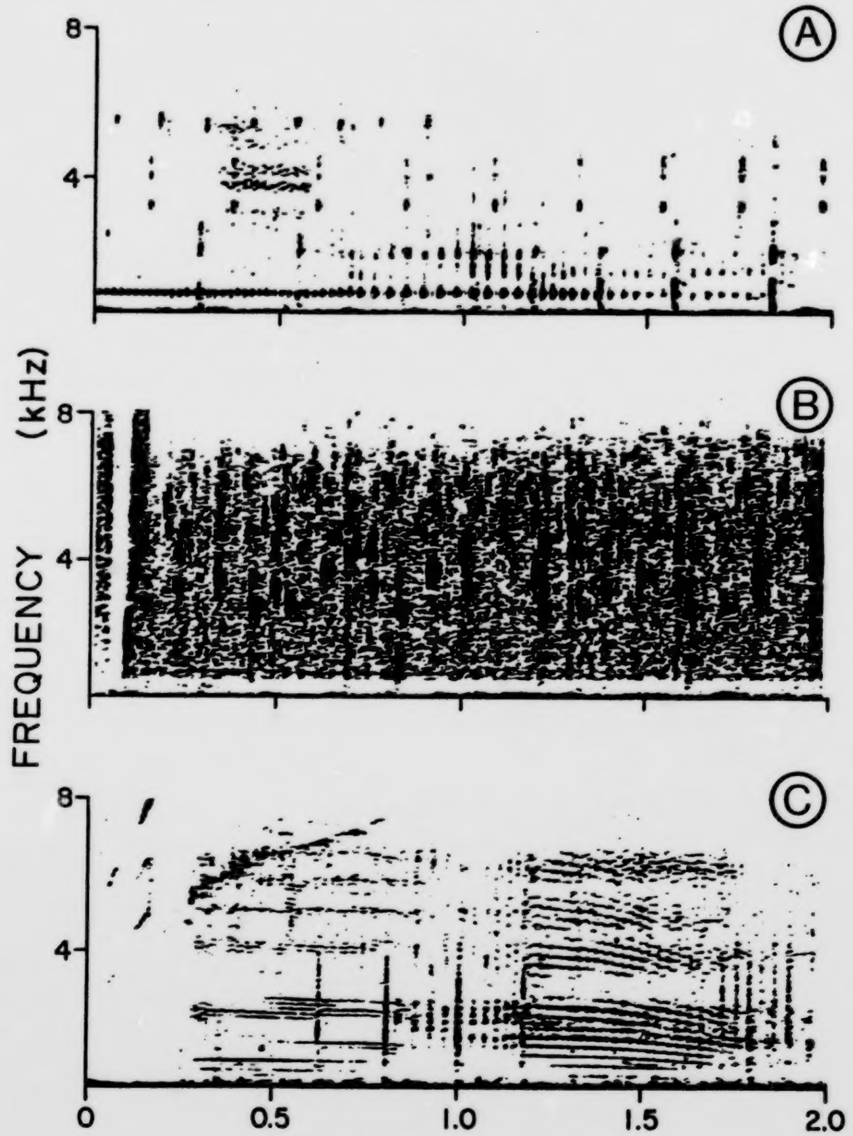


Fig. 5. Examples of narwhal pulsed sounds. (A) Individual click series (B) Dense click 'clatter' against a noisy background of ship sound. (C) Two pulsed tones - the second illustrating a shift from individual broad-band pulses to rapid 'burst' pulsing. The analyzing filter bandwidth of 45 Hz resolves rapid pulsing into side bands related to pulse repetition rate.

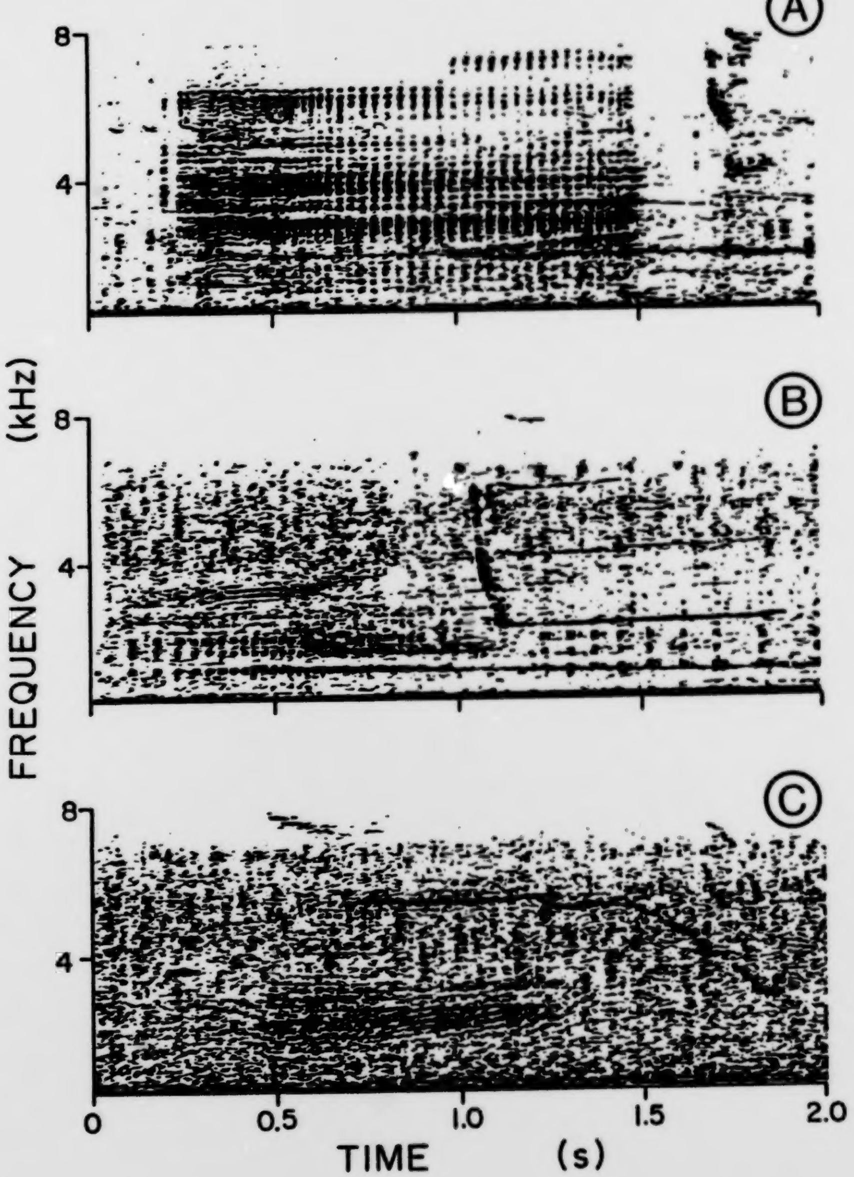


Fig. 6. Examples of narwhal pulsed calls. (A) Wide band coarse 'ratchet' consisting of regular pulses with variable frequency emphasis. (B) Two-part pulsed tone - the second part resolving into widely-spaced resonances giving a squeal-like quality. (C) Pulsed tone accompanied by a descending tonal. Narrow analyzing filter bandwidth of 45 Hz resolves rapid pulsing into side bands related to pulse repetition rate.

Miscellaneous Sounds.--Two additional sounds were heard less frequently in the presence of narwhals and were tentatively attributed to them.

(1) An indistinct low-frequency sound (<100 Hz) thought to be associated with the in-air 'bellow' of adult narwhals. The 'bellow' is apparently created by forcible exhalation through the blow hole and the underwater sound is therefore referred to as the 'blow moan'.

(2) The 'swallowed gulp', a sweep-frequency (700-400 Hz) sound that is easily imitated in the human throat, and which cannot be distinguished from a similar sound of the beluga.

Beluga

Although there are several published descriptions of beluga vocalizations (mostly from captive animals), none are sufficiently quantitative or unambiguous to allow recognition and classification of call types. The beluga produces a remarkable variety of vocalizations, many of complex structure, that intergrade when large numbers are considered. Although several of the calls are stereotypical and easily recognized, most fall within a continuum of sounds with some types more common than others. Basically, as with most odontocete whales, the beluga produces three physically distinct types of sounds--clicks for echolocation, and tonal and pulsed vocalizations. Tonal sounds are the predominant form of vocalization of the beluga and exhibit the most complex array of characteristics.

Tonals (Whistles).--Continuous or non-pulsed waveform characterized by a dominant narrow-band component. The following categories of whistles have been designated somewhat arbitrarily and are not intended to represent mutually exclusive whistle types (Figs. 7 to 10).

1. Level frequency

a		constant
b		broken or morse
c		stepped

2. Shifted frequency

a		falling
b		rising

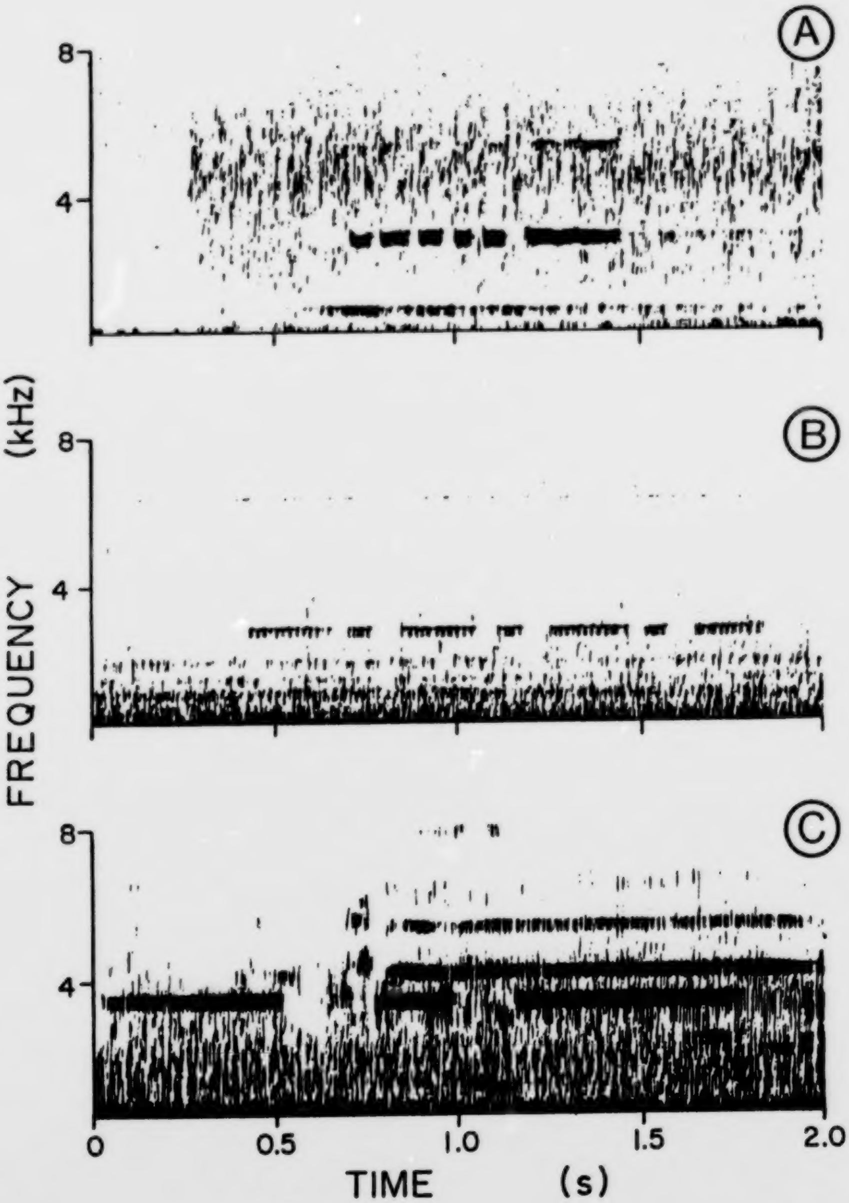


Fig. 7. Examples of level-frequency beluga tonals. (A) Broken 'morse' tonal below band of narwhal 'clatter'. (B) Broken 'morse' tonal above band of ship noise. (C) Constant tonal underlain by a three-part 'morse' tonal and a background of ship noise. Effective analyzing filter bandwidth of 300 Hz.

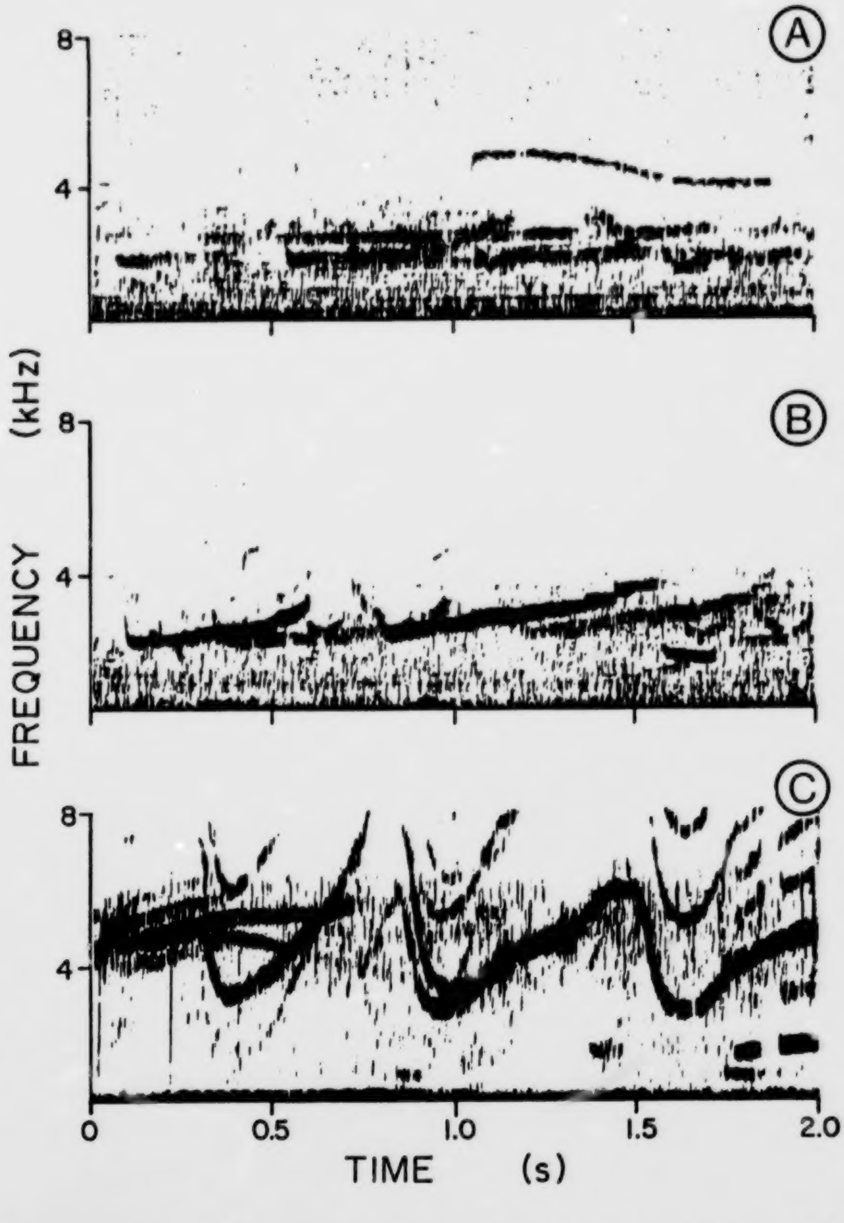
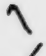
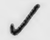
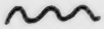
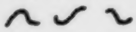
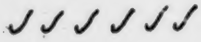
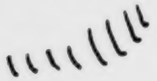
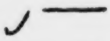
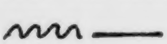
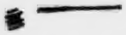
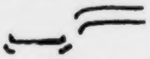


Fig. 8. Examples of shifted tonals of belugas. (A) Descending, rising and constant tonals. (B) Uprising tonals with fainter echoes. (C) Irregular undulating tonals with harmonic components. Analyzing filter bandwidth 300 Hz.

c  inflected down
d  inflected up
e  regular undulating
f  irregular undulating

3. Sweep frequency (chirps and trills)

a chirp
b yelp
c  chirp trains
d  up-trill

The basic whistle types shown above can be combined in different ways to produce the full continuum of sound heard in the wild. For example:  or  . Sounds may be given rasping accents such as  or they may be richly enhanced with harmonic structure,  'chee-a whee', giving them a recognizable or stereotyped quality. These stereotyped sounds were classified as structured tonals. In addition, the whistles differed in (1) frequency emphasis, (2) slope and extent of frequency excursion, (3) amplitude emphasis, (4) duration, and (5) number of components.

Pulsed Sounds (Screams and Buzzes).--Rapidly-pulsed emissions having atonal buzzy qualities at higher frequencies (Fig. 11A), coarse tonal properties with narrow bandwidths and lower frequencies (Fig. 11B) and noisy, strident scream-like qualities over a wide bandwidth (Fig. 11C). Signals often >1 s in duration.

Echolocation Clicks.--Pulsive broad-band clicks emitted in series at variable rates associated with echolocation ranging.

Miscellaneous Sounds.--In addition to the above sounds, belugas also emitted a complex array of sounds that could not be placed in any clear category. Many of these sounds were heard when animals were in close proximity to the hydrophones. The sound quality was often described as grunt-like or bizarre 'horse-laughs' that could not be discerned easily in spectrographic displays of many overlapping, cacophonous sounds. One very distinctive call that was heard frequently was termed the 'swallowed gulp' (easily imitated), a sweep-frequency (700-400 Hz) sound that could not be distinguished from a similar call of the narwhal.

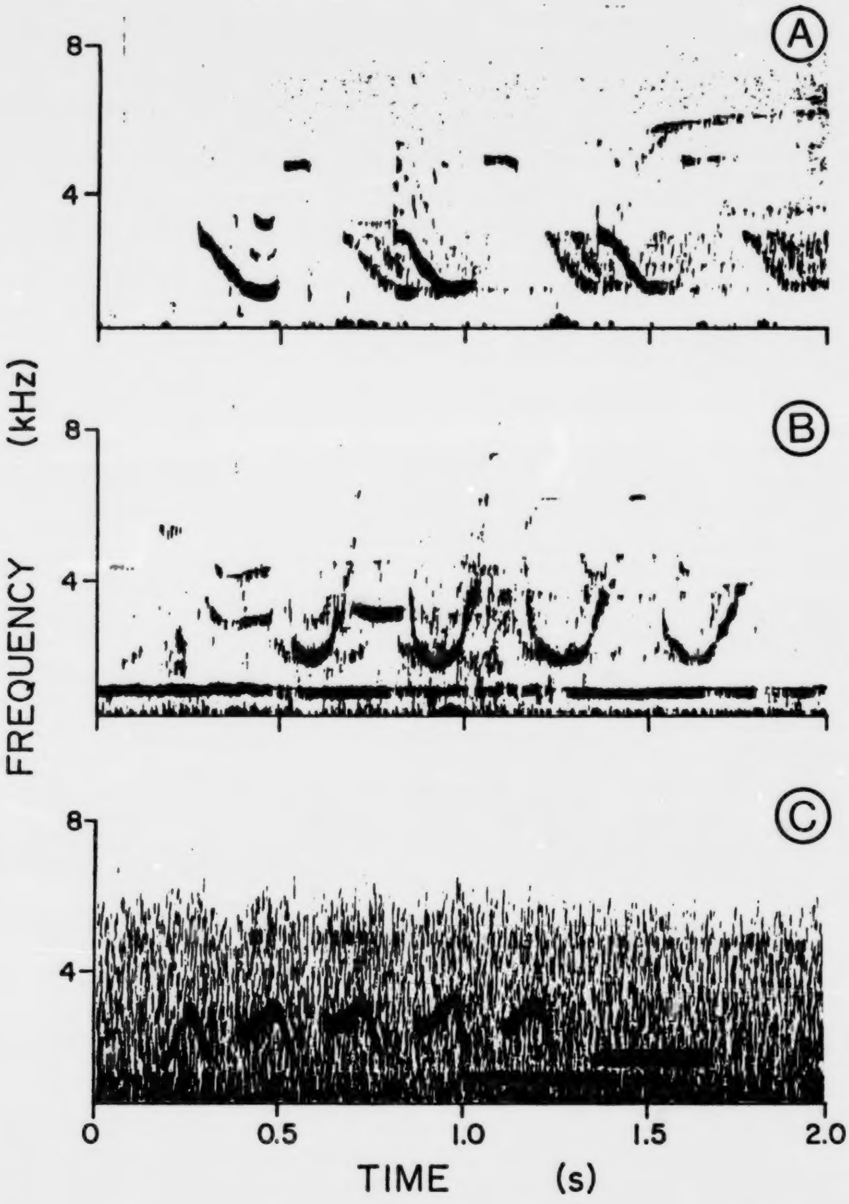


Fig. 9. Examples of structured beluga tonals. (A) Regular-spaced down sweeps interspaced with brief higher frequency components. (B) Stereotyped call underlain by a continuous portion of a bearded seal call. (C) Stereotyped five-part call ending with a linear component.
Analyzing filter bandwidth 300 Hz.

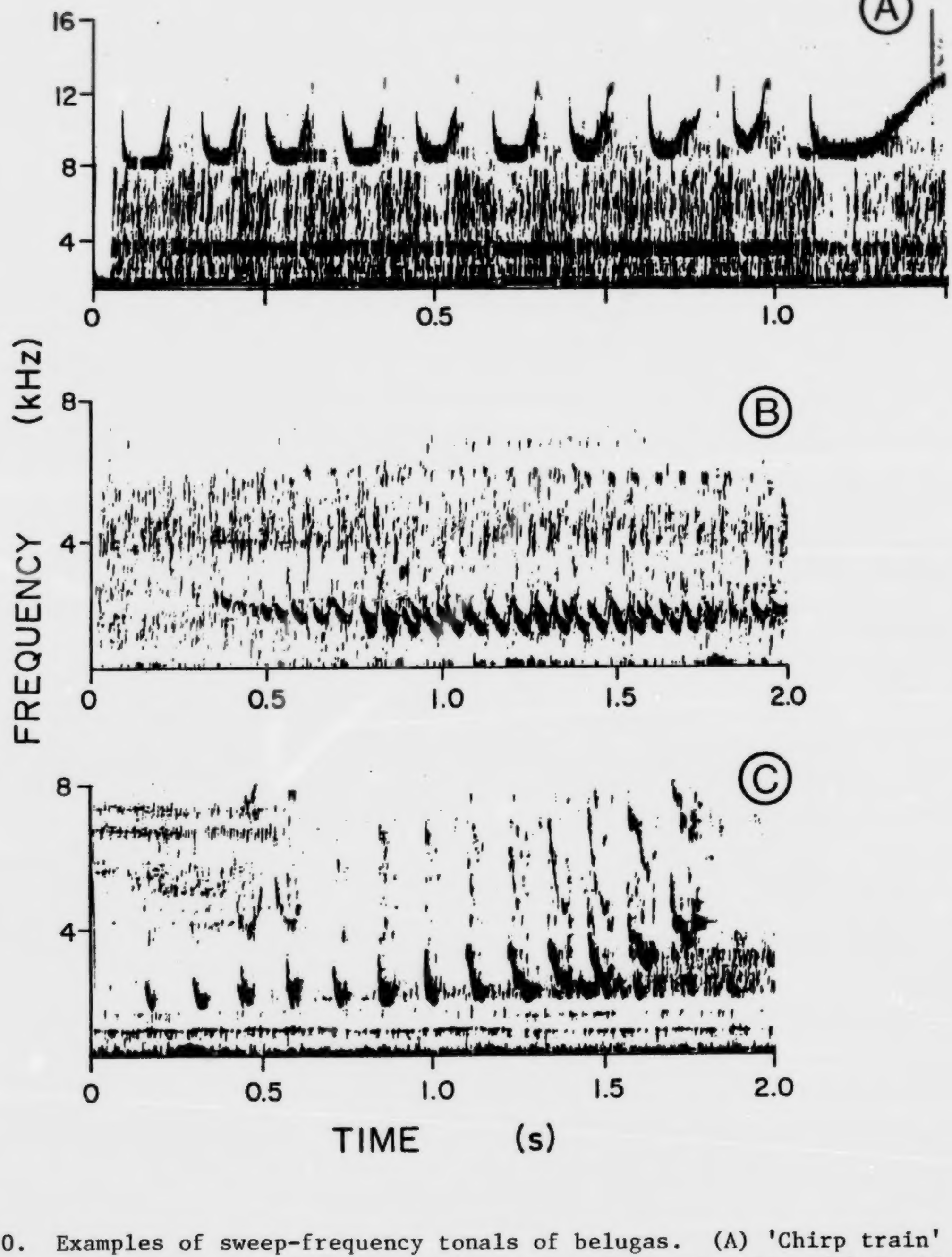


Fig. 10. Examples of sweep-frequency tonals of belugas. (A) 'Chirp train' with background of ship noise and a bearded seal call. (B) Rapid chirp series having a 'warbling' quality beneath a band of narwhal 'clatter'. (C) Stereotyped uptrill preceded by a portion of a pulsed buzz.
Analyzing filter bandwidth 300 Hz.

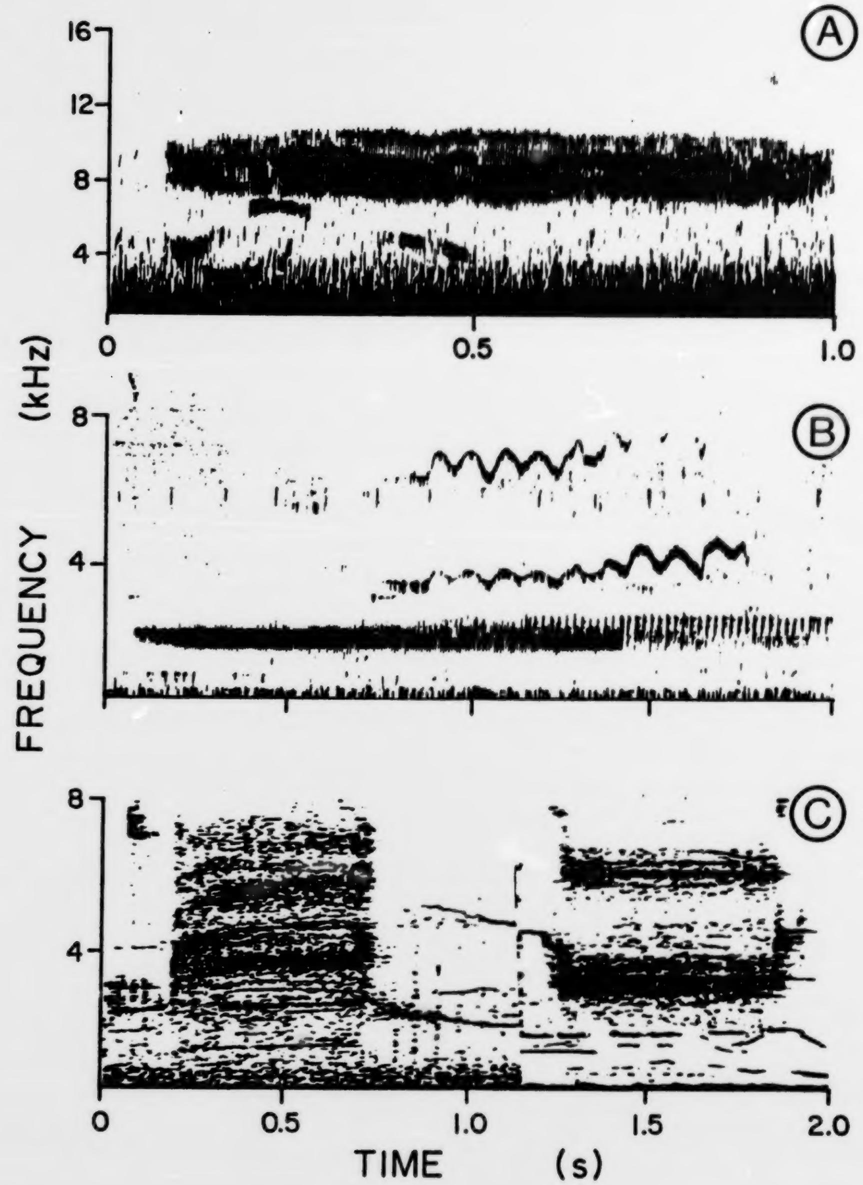


Fig. 11. Examples of beluga pulsed sounds. (A) High-frequency buzz above ship noise band (<4 kHz). (B) Pulsed tonal scream and irregular undulating tonal with harmonics. (C) Two broadband screams. Analyzing filter bandwidth 300 Hz.

Pre-Disturbance Period

(17-24 June)

Distribution and Numbers

Five aerial surveys (17, 19, 20, 21, 23 June) were flown during the pre-disturbance period. Three of these surveys (19, 20, 21 June) were incomplete or provided incomplete data because strong easterly winds had blown a band of pack ice against the ice edge. In some places, particularly along the northern sector, the band of pack ice was up to 10 km wide, obscuring the ice edge and creating a maze-like series of leads that was good habitat for whales, but that could not be surveyed practically by helicopter.

Surveys flown on 17 and 23 June provided the most complete view of whale distribution, although the former survey was marred to some extent by pack ice along the ice edge. Totals of 601 belugas and 119 narwhals were recorded on 17 June (Fig. 12A). All of the narwhals and 87% (526 of 601) of the belugas recorded on 17 June were in the 2 southernmost of the 5 ice edge segments surveyed. The same pattern held for narwhals during the 23 June survey, when 939 belugas and 109 narwhals were recorded. However, belugas were well distributed along the ice edge on that date with substantial numbers occurring in the northern segments (Fig. 13).

Beluga counts were low (115, 138, 267) during the three incomplete surveys flown on 19, 20 and 21 June. However, the narwhal count (115) on 21 June, when the three southernmost segments of the ice edge could be surveyed (Fig. 12B), was comparable to the counts on 19 and 23 June.

In summary, during the pre-disturbance period, about 115 narwhals were recorded consistently along the southern third of the ice edge. Maximum densities (about 8 narwhals/km) were found in the segment that later became the focus of ship disturbances. The maximum number of belugas recorded (939 on 23 June) along the entire ice edge was equivalent to 7.2 animals/km and the maximum density (37.5/km) on any segment was recorded on 21 June in the same area as maximum narwhal densities.

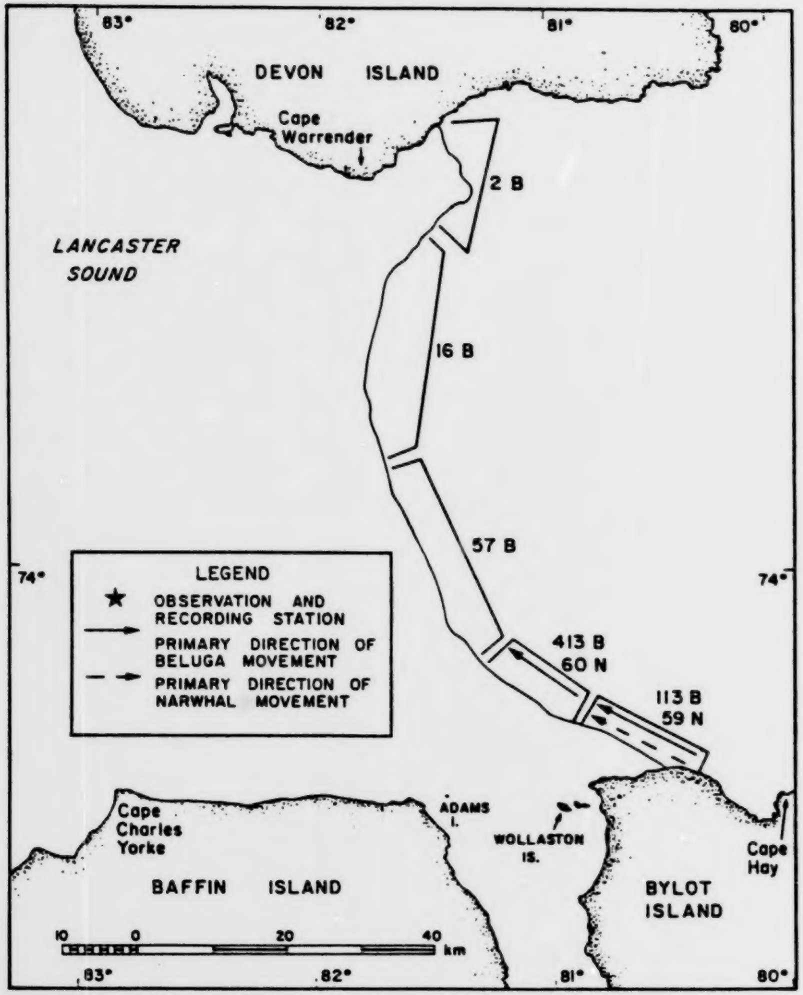

83°
82°
81°
80°
DEVON ISLAND
Cape Warrender
LANCASTER SOUND
2 B
16 B
57 B
413 B
60 N
113 B
59 N
74°
LEGEND
★ OBSERVATION AND RECORDING STATION
PRIMARY DIRECTION OF BELUGA MOVEMENT
PRIMARY DIRECTION OF NARWHAL MOVEMENT
Cape Charles Yorke
ADAMS I.
WOLLASTON IS.
Cape Hay
BAFFIN ISLAND
BYLOT ISLAND
10 0 20 40 km

Fig. 12A. Distribution and numbers of narwhals and belugas recorded during survey 1, 13:47-15:03, 17 June 1983. Totals of 119 narwhals and 601 belugas were recorded. Arrows indicate directions of movement when 75% or more of the whales were moving in the same direction in a particular ice-edge segment (see Methods).

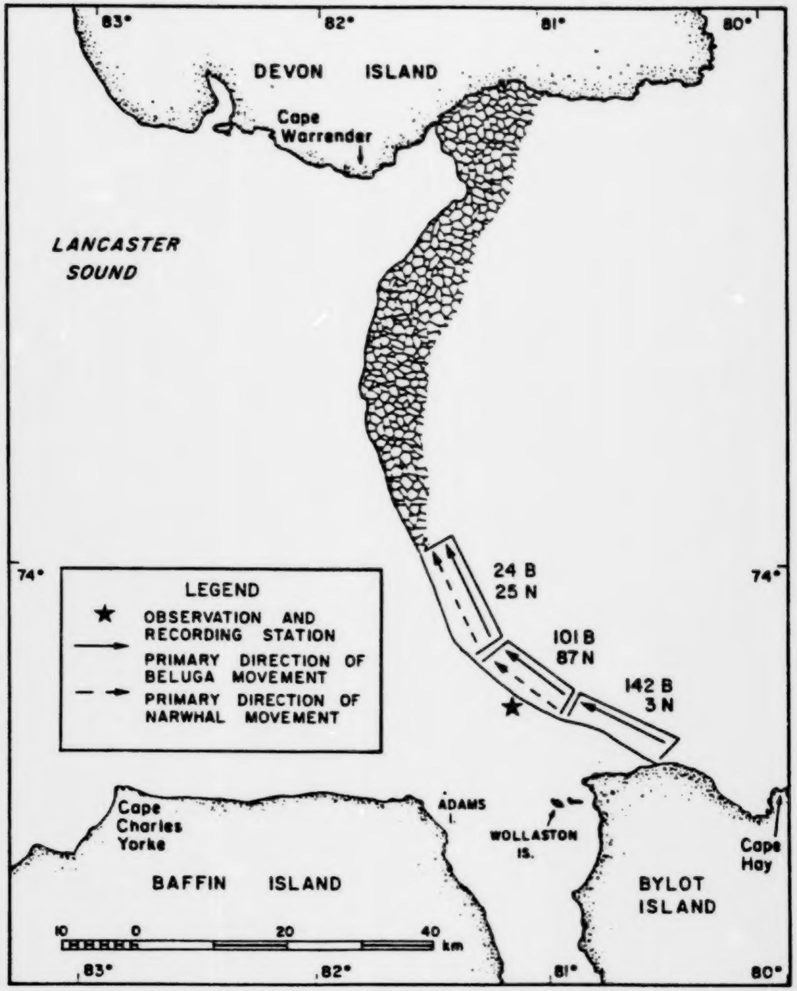

83°
82°
81°
80°
DEVON ISLAND
Cape Warrender
LANCASTER SOUND
24 B
25 N
101 B
87 N
142 B
3 N
74°
LEGEND
★ OBSERVATION AND RECORDING STATION
PRIMARY DIRECTION OF BELUGA MOVEMENT
PRIMARY DIRECTION OF NARWHAL MOVEMENT
Cape Charles Yorke
ADAMS I.
WOLLASTON IS.
Cape Hay
BAFFIN ISLAND
BYLOT ISLAND
10 0 20 40 km

Fig. 12B. Distribution and numbers of narwhals and belugas recorded during survey 4, 19:38-20:11, 21 June 1983. Totals of 115 narwhals and 267 belugas were recorded along the three southern segments of the ice edge. Extensive bands of pack ice (to 10 km wide) precluded surveys along the northern portion of the ice edge.

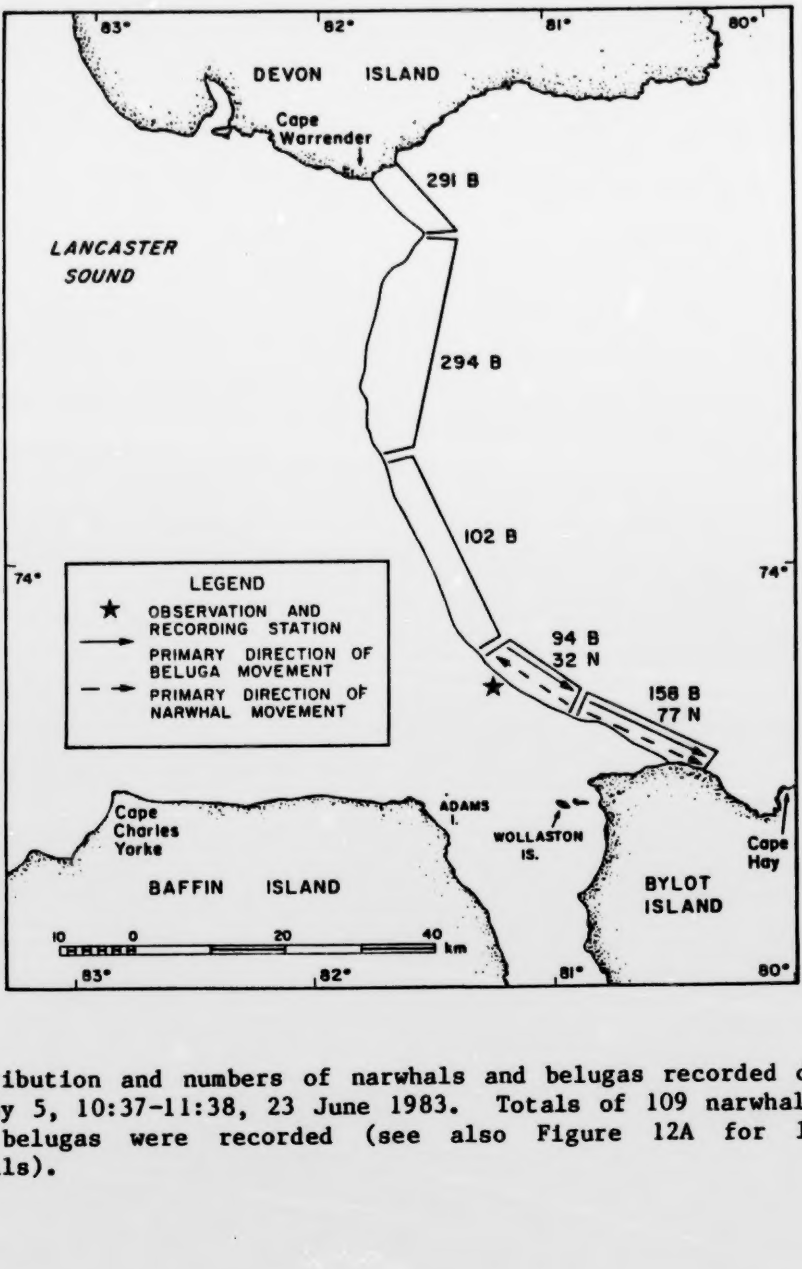

83°
82°
81°
80°
DEVON ISLAND
Cape Warrender
291 B
LANCASTER SOUND
294 B
102 B
74°
74°
LEGEND
★ OBSERVATION AND RECORDING STATION
PRIMARY DIRECTION OF BELUGA MOVEMENT
PRIMARY DIRECTION OF NARWHAL MOVEMENT
94 B
32 N
158 B
77 N
ADAMS I.
WOLLASTON IS.
Cape Charles Yorke
BAFFIN ISLAND
BYLOT ISLAND
Cape Hay
10 0 20 40 km
83°
82°
81°
80°

Fig. 13. Distribution and numbers of narwhals and belugas recorded during survey 5, 10:37-11:38, 23 June 1983. Totals of 109 narwhals and 939 belugas were recorded (see also Figure 12A for legend details).

Movement Patterns

Data on whale movements were collected during both the aerial surveys and the ice-based watches. However, the scopes of these two types of data differ considerably. The aerial surveys provide an instantaneous assessment of the direction of movement of whales distributed all along the ice edge. The ice-based watches provided observations of whale movements at a fixed point along the ice edge over time.

Most of the directed movements observed during aerial surveys in the pre-disturbance period occurred along the southern portion of the ice edge, including the Navy Board Inlet ice edge. Belugas were observed moving north along this part of the ice edge on 17 and 21 June, and south on 23 June. Narwhals were also moving north on 17 and 21 June, but were moving both north and south on 23 June (Figs. 12 and 13).

Most of the belugas and narwhals observed during aerial surveys were involved in directed movements, close and usually parallel to the ice edge. For example, on 23 June the majority (90%) of belugas were involved in directed movements and the others were either circling, diving beneath the ice or resting. Movements of belugas often tended to be unidirectional over long segments of the ice edge; for example on 23 June the majority (89%) of belugas in the southern segments were moving south, although movements in the northern segments were bi-directional. Narwhal movements tended to be more casual and less directed than those of belugas. During the five pre-disturbance surveys 19% (40 of 208) of the narwhals whose movements were recorded were circling, diving under the ice, or resting at the surface near the ice edge.

Data on whale movements collected by ice-based observers indicate that narwhals and belugas move back and forth along the ice edge (Fig. 14). During the 45 hours of pre-disturbance ice edge watches, 108 narwhals moved north and 117 moved south past observers at the ice edge. The corresponding figures for belugas were 241 moving north and 299 moving south. In general, it appears that the movements of narwhals and belugas were synchronous. At

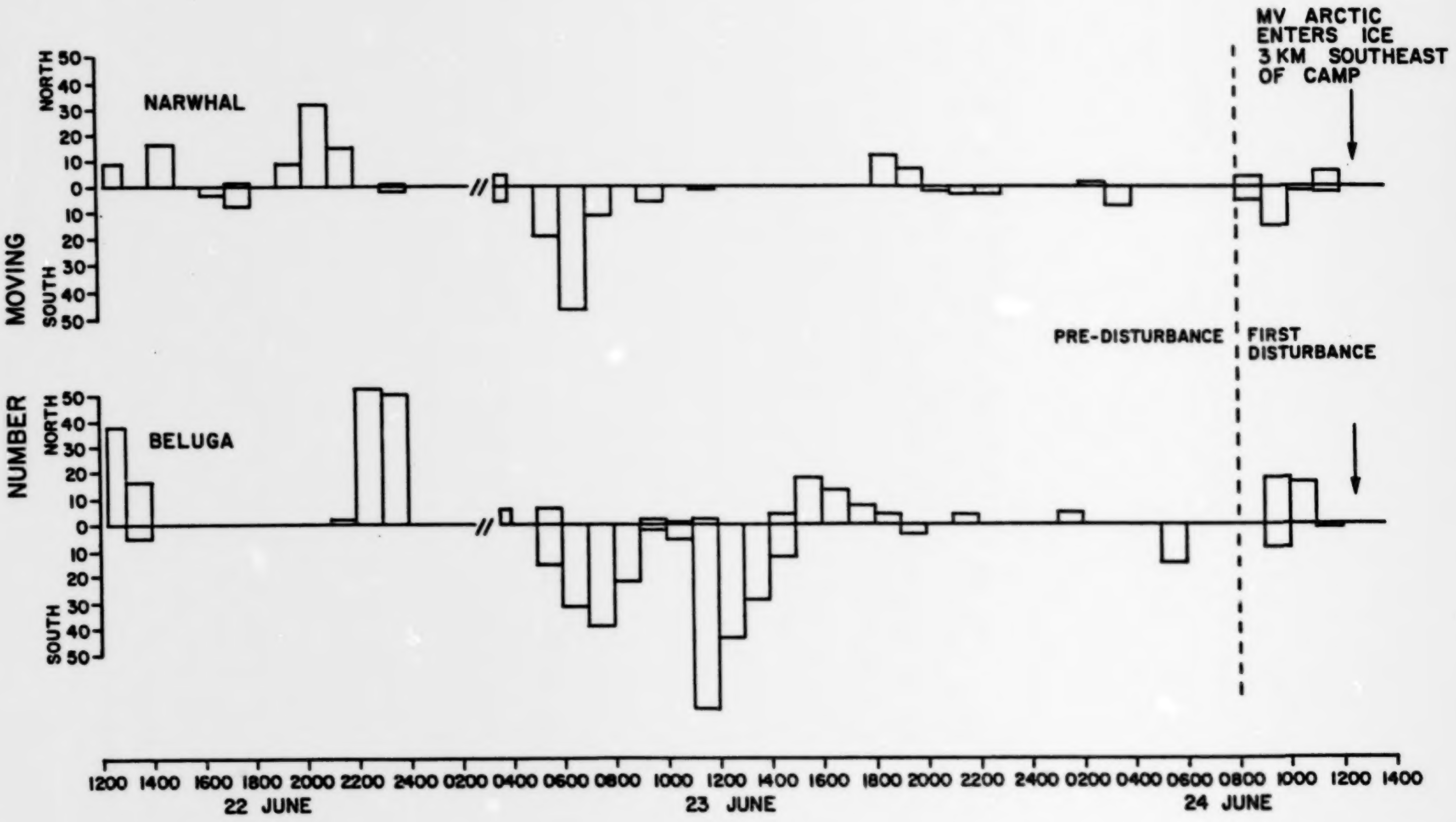


Fig. 14. Directional movements of narwhals and belugas recorded during ice-based watches from 22-24 June 1983, prior to the entry of the MV Arctic into the ice.

any given time narwhals and belugas were usually moving in the same direction past the observers on the ice edge, although peak movements of the two different species did not coincide.

Association With the Ice Edge

The close association of narwhals and belugas with the Lancaster Sound ice edge was evident during all of the aerial surveys. The observer closest to the ice edge (i.e. within 400 m) recorded 75.0% of all belugas and 64.3% of all narwhals seen.

During the pre-disturbance period, proximity to the ice edge was recorded for 242 narwhals and 542 belugas. From the low vantage point of the observers, whales were only visible to distances of a few hundred metres. Within this limited range, the data (Fig. 15) indicate that during undisturbed periods narwhals were about equally likely to be found in each of the four distance categories examined (<10 m, 11-50 m, 51-100 m, 101-500 m). Belugas showed a slight tendency to be found in the distance categories farther from the ice edge. Thirty-seven percent (203 of 542) of the belugas were between 101 and 500 m of the ice edge compared to only 10% between 0 and 10 m from the edge. These results may be somewhat biased by the greater visibility of the lighter coloured belugas than narwhals, especially at greater distances and during periods of poor lighting conditions.

Age and Sex Composition

A total of 102 (28%) of the 343 narwhals recorded during aerial surveys flown on 17, 21 and 23 June were classified by age and sex. Ninety-four percent were adult males, and 6% were females (Fig. 16). No calves or immatures were recorded.

A total of 721 (47%) of 1540 belugas recorded during surveys flown on 17 and 23 June were classified according to age and sex. Twenty percent were adult males, 41% were adults unaccompanied by immatures, 11% were females (see Methods for criteria), 15% were immatures and 13% were unspecified

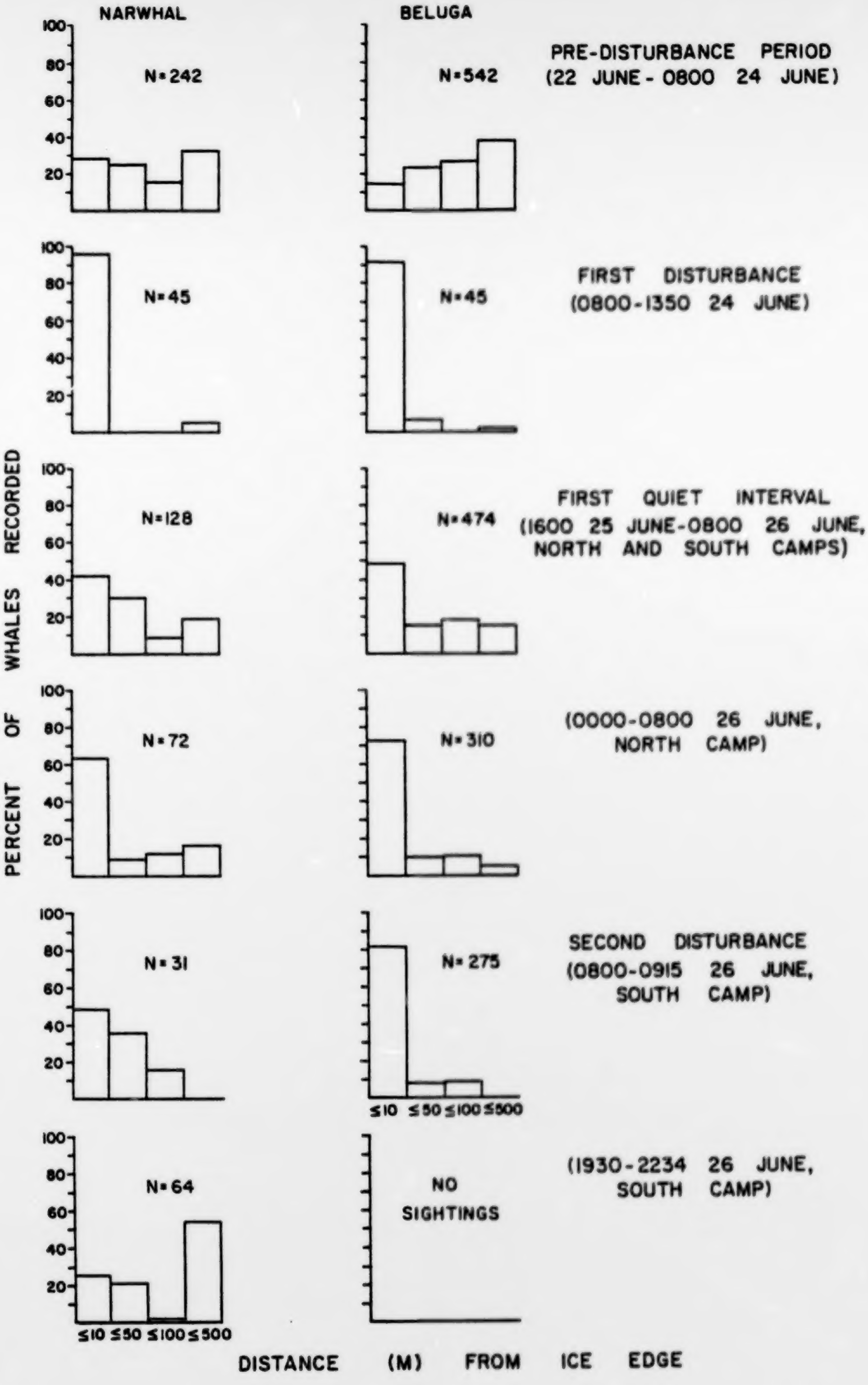


Fig. 15. Distances at which narwhals and belugas were recorded from the ice edge during various periods from 22-26 June 1983.

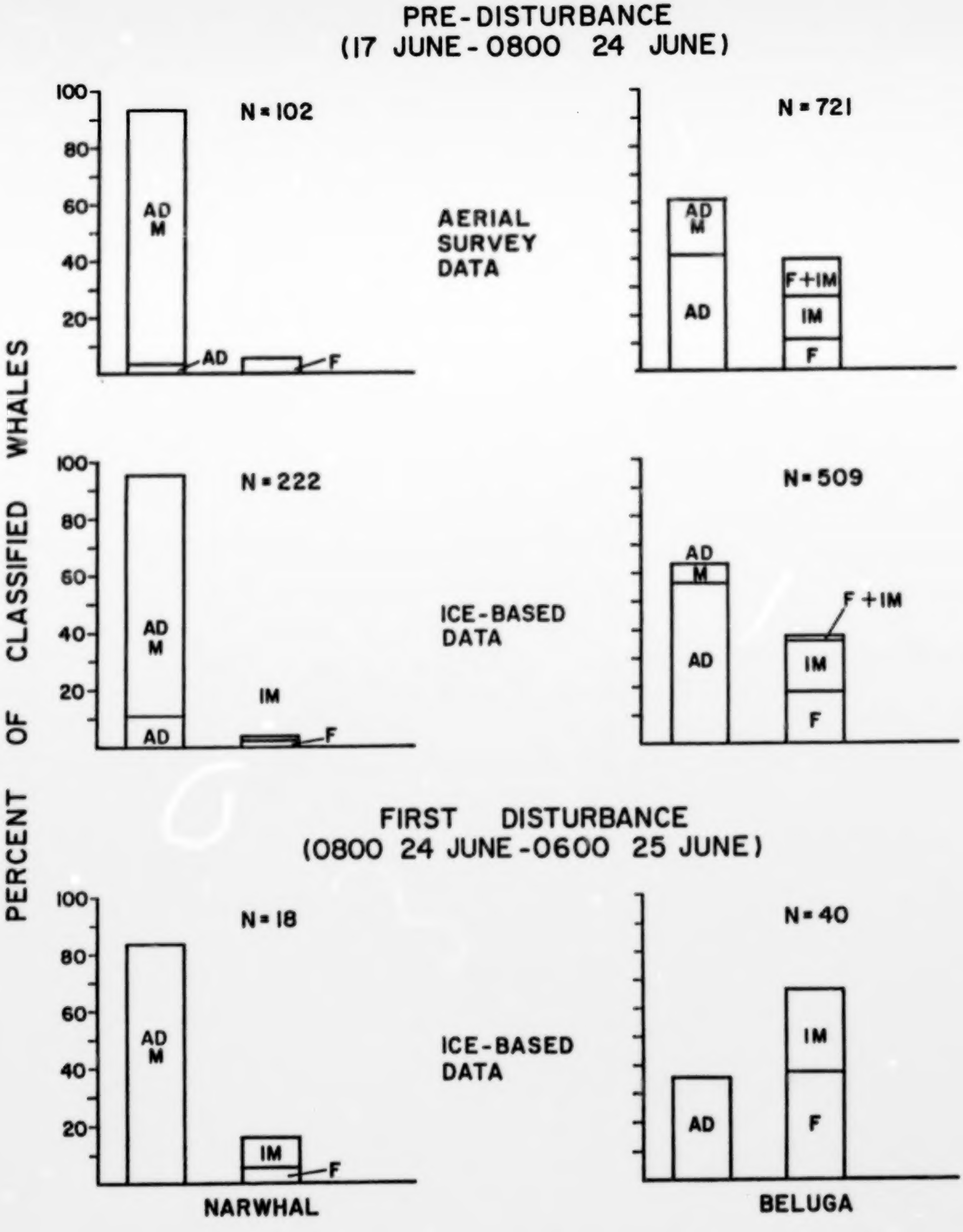


Fig. 16. Sex/age composition of narwhals and belugas recorded by aerial and ice-based observers during the pre-disturbance and first disturbance periods.

females and immatures (Fig. 16). The survey on 21 June was excluded from the beluga calculations because the northern part of the ice edge where belugas were expected to be present could not be surveyed.

Forty-five hours of ice edge observations were conducted during the pre-disturbance period. The age and sex structure of 222 (89%) of the 250 narwhals recorded is shown in Figure 16. Ninety-six percent of the classified narwhals were adult males, 3% were females and 1% were immatures. These data are in good agreement with those obtained during aerial surveys.

A total of 509 (93%) of the 548 belugas recorded during ice-edge watches were classified by age and sex. Seven percent of the belugas were males, 55% were adults unaccompanied by immatures, 18% were females, 18% were immatures and 1% were unspecified females and immatures (Fig. 16). These observations are in general agreement with the aerial observations (i.e. 61-62% were unaccompanied adults) but from the aerial perspective, pod integrity was more evident and sex composition was more likely to be judged as male.

Vocal Behaviour

The sounds of narwhals and/or belugas were present in all 47 10-min recording sessions prior to the arrival to the ships. Most sessions were saturated with whale sounds along with the frequent calls of the bearded seal (Erignathus barbatus). Narwhals were audible in 39 of the 47 sessions and belugas in 41. Judging from the signal strength of the recorded calls, narwhals were in close proximity to the recording site in 33 of the 47 sessions and belugas were in close proximity in 27 sessions.

Narwhal

The presence of narwhals was most evident by their click emissions; most recordings were saturated with a dense clatter of overlapping click series. The other predominant narwhal sound, the pulsed call, usually, but not always, accompanied the click series. A total of 76 pulsed calls were discerned in the 24 spectrographic segments (each 30 s in duration) that were analyzed in the pre-disturbance period. Pulsed calls often occurred in bouts (max. 16 per 30 s) with many individuals apparently contributing. There was no evident diel pattern in the frequency of occurrence of pulsed calls, although it is quite likely that any pattern would be obscured by other uncontrolled factors. Tonal vocalizations were heard relatively infrequently during those sessions when other narwhal sounds were predominant. 'Swallowed gulps' were also heard in association with other narwhal sounds but these could not be distinguished from a similar sound of the beluga.

Beluga

The presence of belugas in underwater recordings was most evident from their tonal emissions. A total of 174 calls were discerned in the 24 segments of spectrographic analyses. The majority of the calls were of the level frequency type (43%) with chirps (17%), up-rising (13%), undulating (9%) and structured (8%) tonals accounting for most of the other call types. Only one pulsed signal, a high-frequency buzz, was discerned in the spectrographic analysis. The repertoire of calls recorded during the pre-disturbance period was mostly from animals that were moving along the ice edge. However, the strongest signals and densest vocal activity (max. 17 calls per 30 s) occurred on those occasions (e.g., 22 June, 13:00) when belugas were involved in circling movements and dives that were directed beneath the ice edge. There was no evidence that they closely investigated the hydrophones (as they often did later), which were sometimes located within 200 m of the ice edge.

Ambient Noise

A large number of samples of ambient background noise in the absence of ship noise were collected during this study. Twenty-five samples at two hour intervals have been analyzed but only representative analyses are presented in this report. Band level analyses for the 25 samples are presented in Appendices A and B.

Ambient noise levels at the ice edge during the pre-disturbance period ranged from 93 to 107 dB//1 μPa in the 20-1000 Hz band at a depth of 20 m. The equivalent measurements at 3 m depth ranged from 82 to 104 dB//1 μPa.

The lower levels at the shallower depth are expected close to the acoustically 'soft' boundary at the surface.

It is of interest to note that ambient noise levels were higher at the Lancaster Sound ice edge in 1983 than at the Admiralty Inlet ice edge that we studied in Phase 1 of the program in 1982. The ambient levels in 1982 ranged from 85 to 92 dB//1 µPa in the 20-1000 Hz band at 20 m depth. These differences are due to the calmer conditions that prevailed in 1982 and to the fact that larger numbers of animals were present along the Lancaster Sound ice edge in 1983.

Similarly, the comparisons of ambient noise at the ice edge and at the satellite station 11 km from the edge on 24 June 1983 indicated that noise levels were higher at the ice edge. In the 20-1000 Hz band, levels at the ice edge ranged up to 10 dB higher than at the satellite station. It is of interest that even though the satellite camp was 11 km from open water, calls from bearded seals and belugas were prominent in the ambient noise.

To evaluate various inputs to ambient noise it is useful to examine the distribution of sound pressure over the entire frequency range of the recording equipment. Figure 17 presents the sound pressure spectrum for the 20 m depth at the ice edge at 14:58 on 20 June. The reader should note that the graphs in Figure 17 present spectrum level data rather than band level data. The graphs show the sound pressure in 1 Hz bands rather than in the wider bands (20-1000 Hz) previously discussed. Thus, the apparently lower levels in the spectra in Figure 17 reflect different analysis units, not lower noise levels. In fact, the 20-1000 Hz band level for this sample is 107 dB//1 µPa.

The ambient noise spectrum shown in Figure 17C is dominated by various whale calls at frequencies between 1 and 15 kHz. The source of the low frequency peak at 19 Hz (Fig. 17A) is probably ice noise. During the four days before the ships arrived, strong peaks in the ambient noise were often observed between 14 and 28 Hz, and we know that ice under pressure can produce tones in that frequency range.

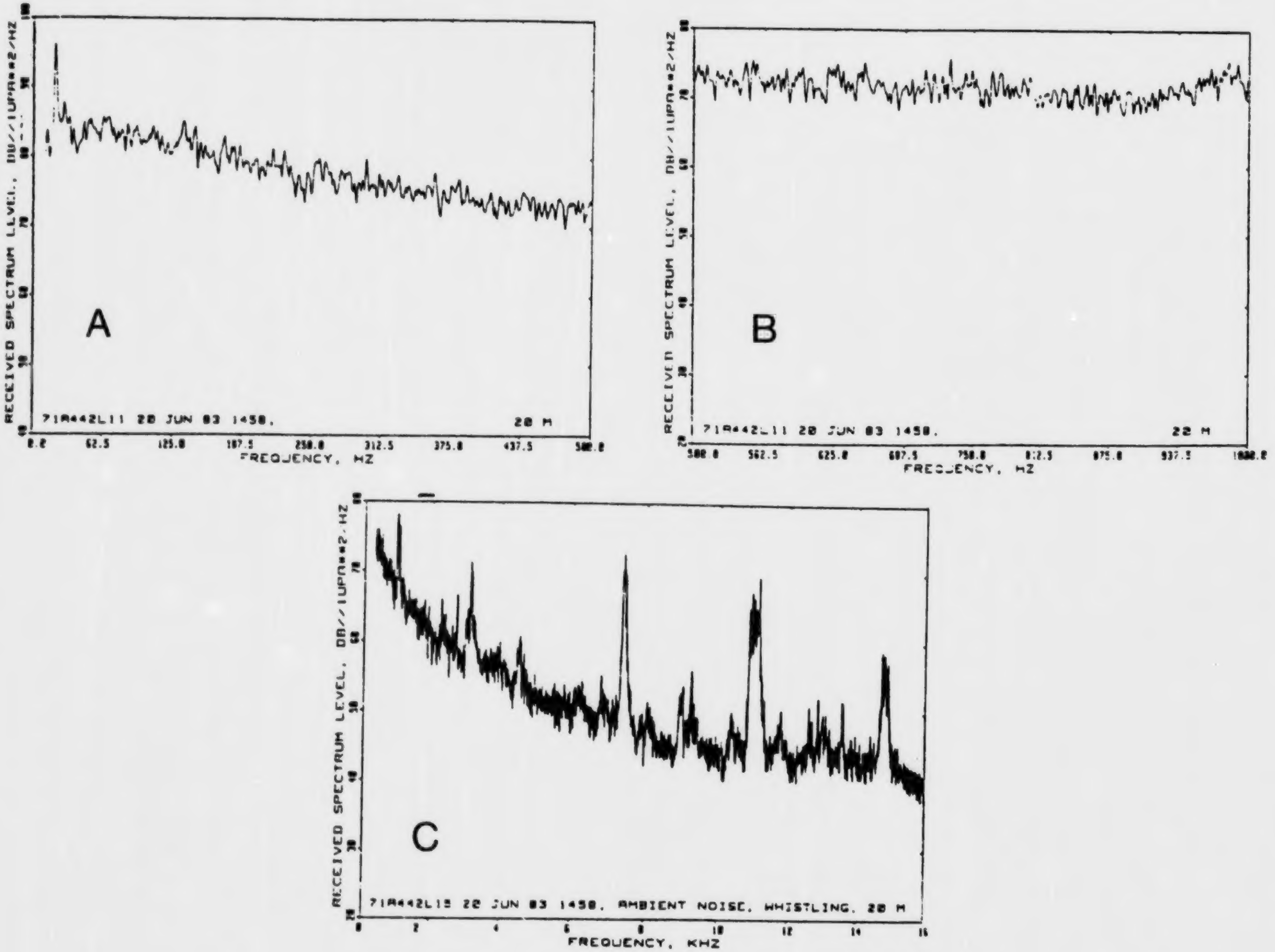


Fig. 17. Ambient noise spectra at the ice edge, 14:58, 20 June 1983; 20 m depth. Whale sounds appear between 1 and 15 kHz. In the graphs for the frequency ranges 0-500 and 500-1000 Hz the frequency resolution is 1.7 Hz; in the 0-16 kHz range the resolution is 27.2 Hz. For the low-frequency graphs (to 1000 Hz), 8.5 s of sounds are analyzed; for the high frequency graph, because of the higher sampling frequency, only 0.5 s are analyzed.

A second example of ambient noise spectra is presented in Figure 18. This figure also shows the low frequency peak that is thought to be caused by ice. It also illustrates elevated noise levels in the 400 to 600 Hz range. These levels are caused by bearded seals calling.

In the following sections of the report we present additional information on received noise levels that represent both natural ambient conditions and situations where ship noise is present and often dominates. For convenience and consistency we have presented the levels in the 20-1000 Hz band at a depth of 20 m. It is realized, however, that this band is probably not the most important to belugas and narwhals since their hearing (beluga-tested; narwhal-assumed) is most sensitive at higher frequencies. The reader who is interested in more detailed analyses is referred to Appendix B where the received levels in various one-third octave bands for higher frequencies are presented. In ship dominated noise, the levels in the higher frequency bands (>1 kHz) tend to have a stable and predictable relationship to the level in the 20-1000 Hz band. Hence, the level in this lower frequency band is a useful index to higher frequency ship noise. In the absence of information on the frequency ranges that are most important to narwhals and belugas, it is simplest to use the low frequency band consistently.

First Disturbance Period
(08:00 24 June to 09:07 25 June)

Ship Position and Received Noise Levels

At 02:00 (EDT) on 24 June, the MV Arctic was about 250 km from our recording station and was not a factor in the ambient noise which, at the time, was dominated by water and ice noise associated with 10-12 knot winds, along with bearded seal calls. The earliest indication of the presence of sounds from the Arctic at the ice edge was at 06:01 when the ship was 132 km from the hydrophone. A weak tone (23 dB//1 µPa) was present at 105 Hz. This tone was probably the second harmonic of the major 53 Hz tone that became evident when the ship was closer. [The 53 Hz tone is related to the cylinder firing rate of the Arctic's main engine.]

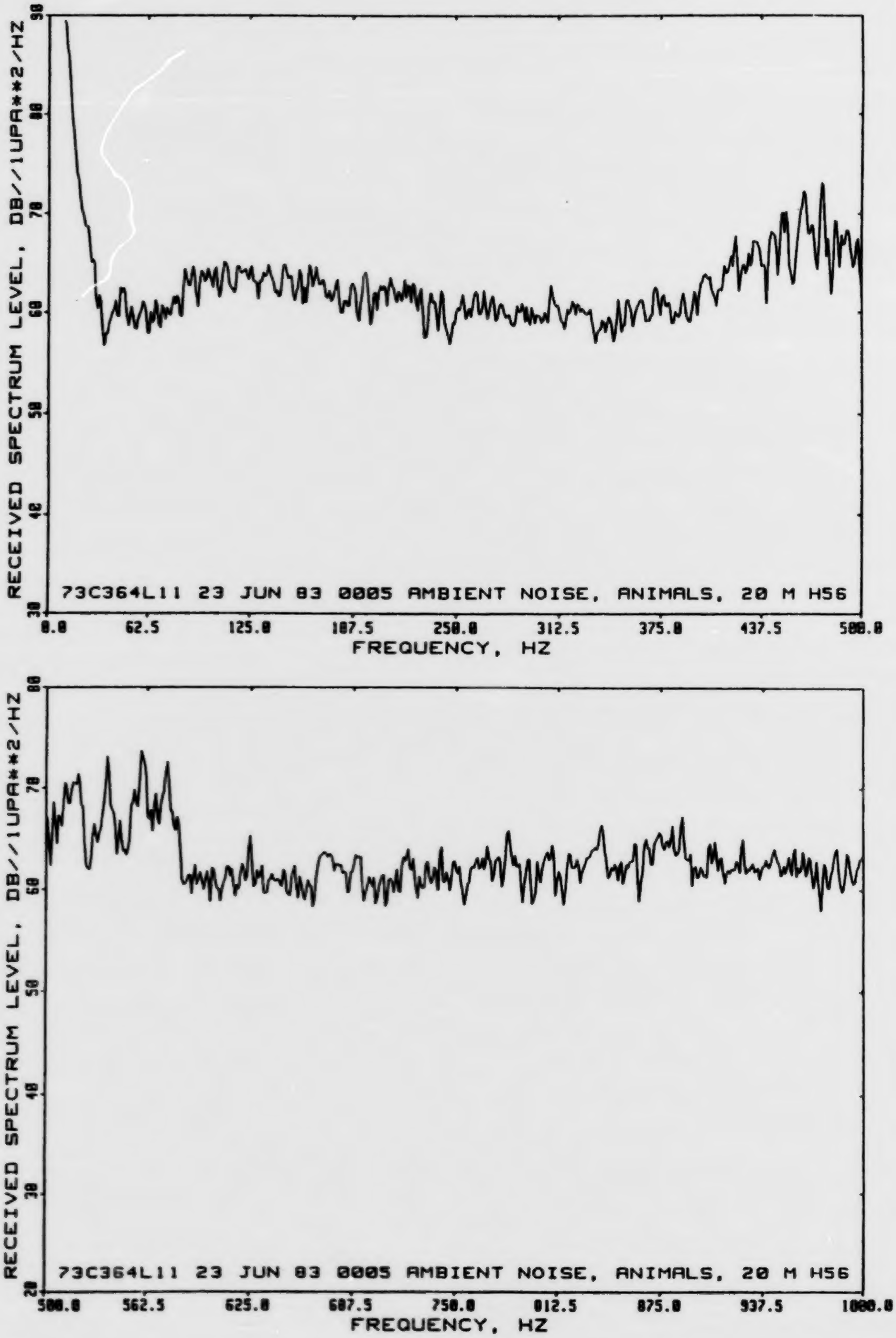


Fig. 18. Ambient noise spectra at the ice edge, 00:05, 23 June 1983; 20 m depth.

By 08:02, the Arctic was distinctly, though faintly, audible to the human ear listening to the hydrophone signal. Several small line components are present in the sound pressure spectrum at frequencies below 200 Hz (Fig. 19). The second harmonic was 81 dB//1 µPa at 101 Hz and the 20-1000 Hz band level was 101 dB/11 µPa. At this time the Arctic was 84 km from our hydrophone. The spectra for 10:00 when the ship was 47 km distant are also presented in Figure 19. The spectral peaks of ship noise were more prominent and extended up to about 350 Hz. The second harmonic tone was 86 dB//1 µPa at 102 Hz and the 20-1000 Hz band level was 105 dB//1 µPa.

The noise spectra received from the Arctic at distances of 9.9 and 5.1 km are presented in Figure 20. The 53 Hz tone is prominent at 9.9 km but is submerged in the cavitation noise in the spectrum at 5.1 km. The MV Arctic penetrated the ice edge at 12:20. At 13:05, the ship had begun backing out of the ice at the range of 5.1 km. The 20-1000 Hz band level noise when the Arctic was moving forward at 9.9 km was 125 dB//1 µPa. In reverse at 5.1 km the band level noise was 134 dB//1 µPa; the spectral peaks were submerged in broadband noise, which had a strong rapping quality.

Waterfall spectrograms of received noise from the Arctic are presented in Figure 21. The 53 Hz tone was prominent in the upper graph. The lower graph illustrates a tone at 207 Hz. This tone was prominent in our 1982 studies; it apparently is related to the 'bubbler system' that is used on the Arctic to reduce friction between the hull and ice during ice-breaking operations. The nominal rotation speed of the bubbler compressor is 14,000 rpm, or 233 rps. Thus, an acoustic tone is expected at 233 Hz. In fact, the tone occurs at 207 Hz.

At its closest point of approach, the Arctic was breaking ice at a measured distance of 672 m from our hydrophone. Sound spectra for forward and reverse modes are presented in Figure 22. Overall, noise in the 20-1000 Hz band was 130 dB//1 µPa going forward and 136 dB in reverse. The 207 Hz tone was prominent in each case, although the tone was often not prominent when the Arctic was in reverse.

The Arctic shut down its main engine at 09:07 on 25 June.

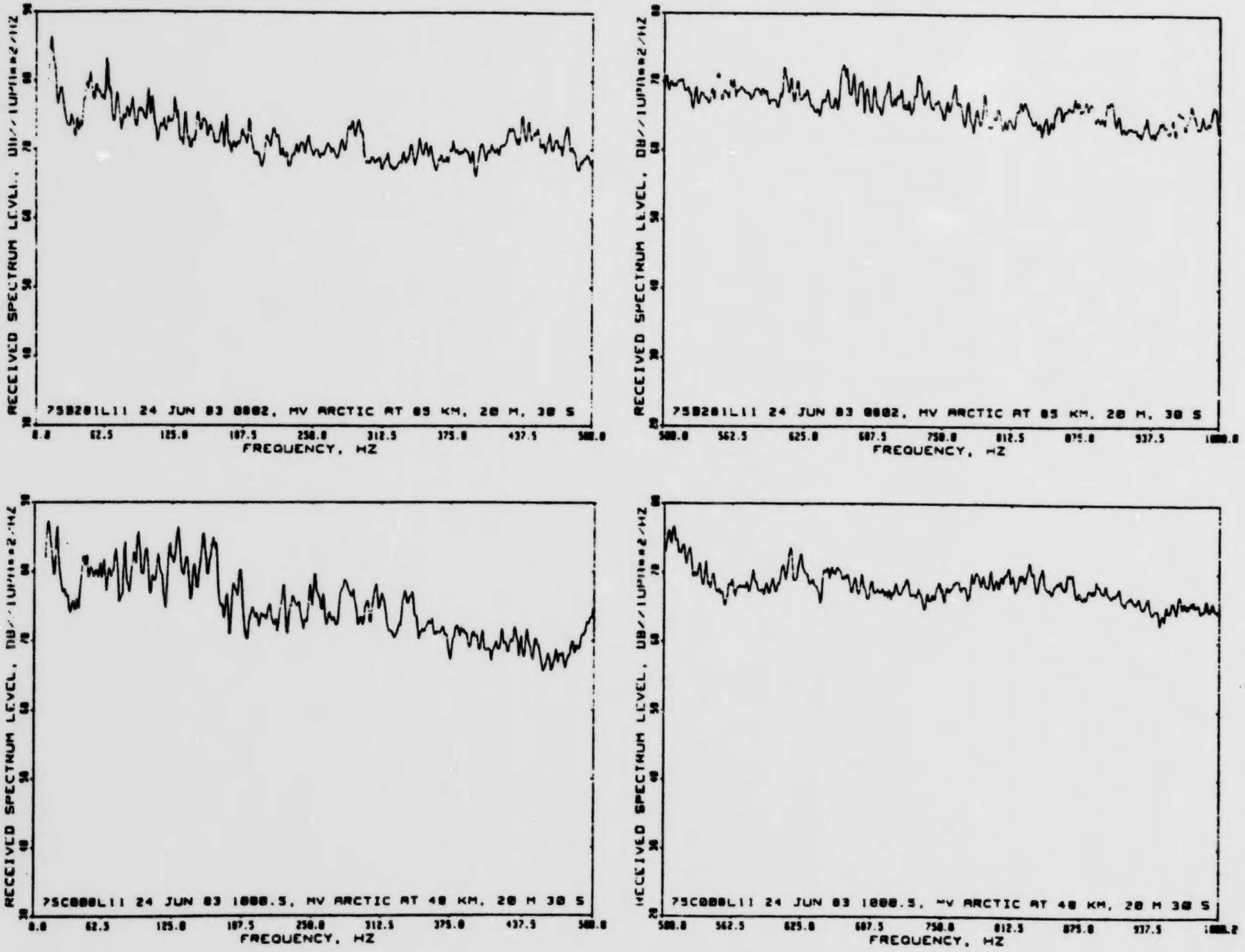


Fig. 19. Noise spectra with the MV Arctic at ranges of 84 and 47 km, 24 June 1983, 08:02 and 10:00.5; hydrophone depth 20 m. Sample length is 30.5 s.

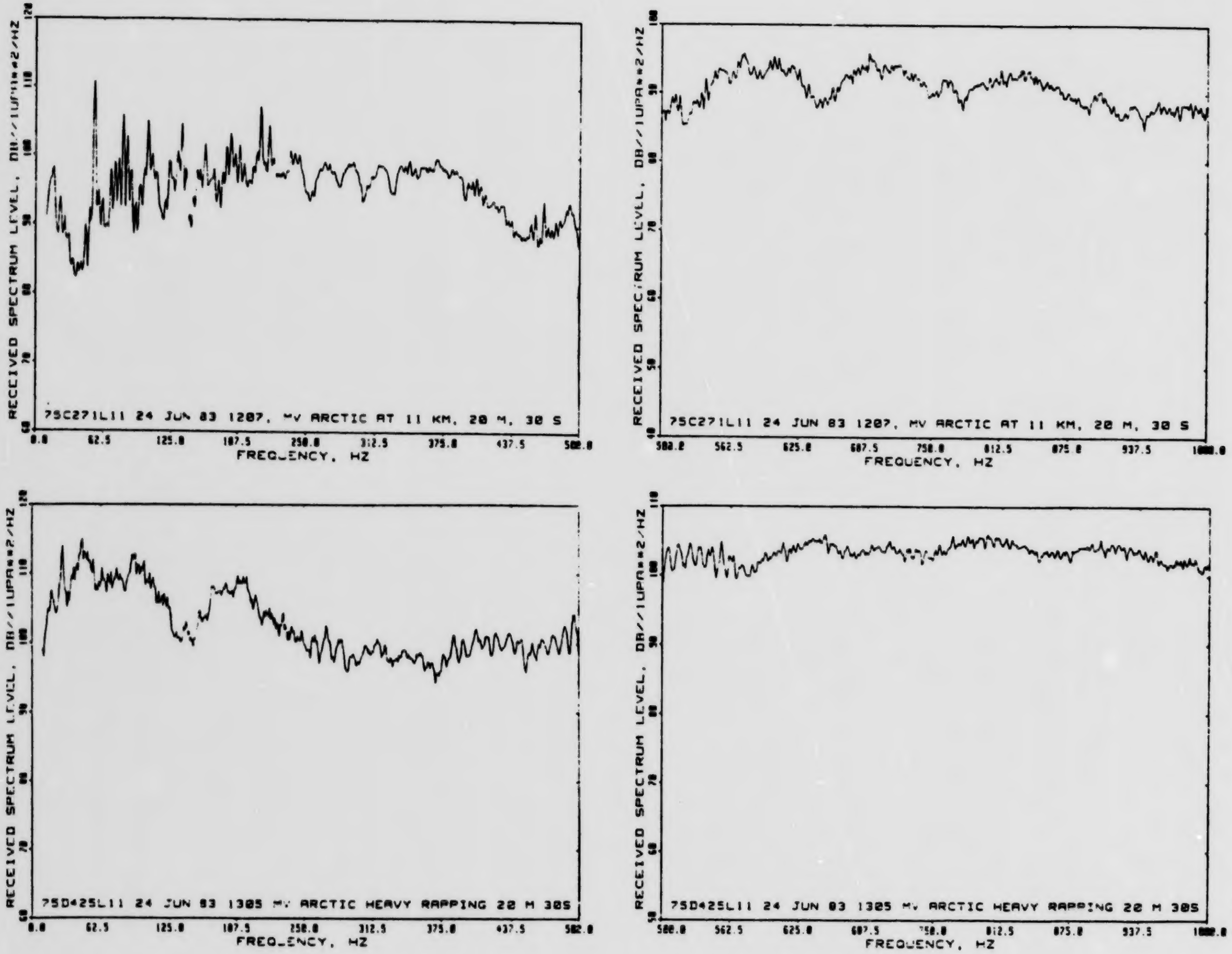
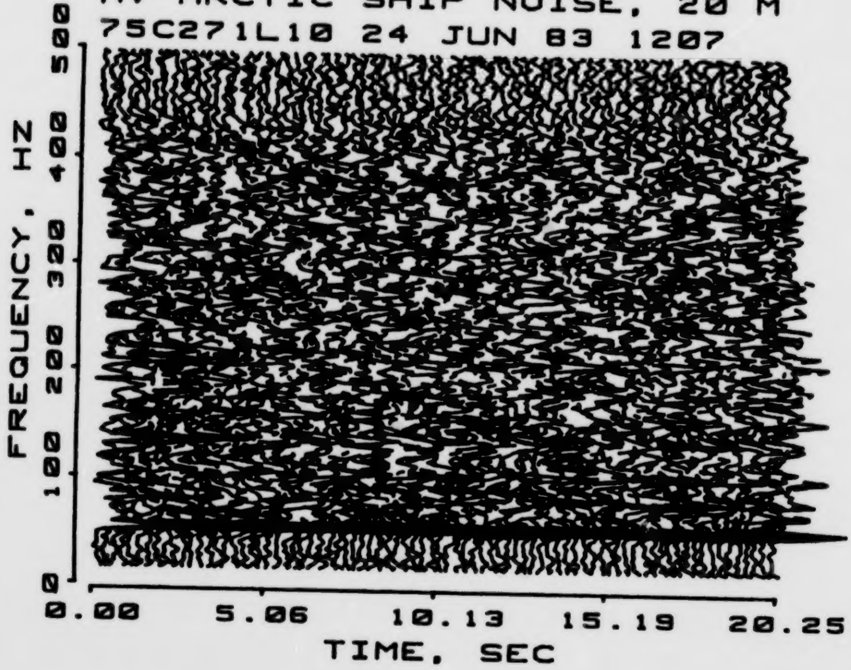


Fig. 20. Spectra for MV Arctic at ranges 9.9 and 5.1 km, 20 m depth, 12:07 and 13:05, 24 June 1983.



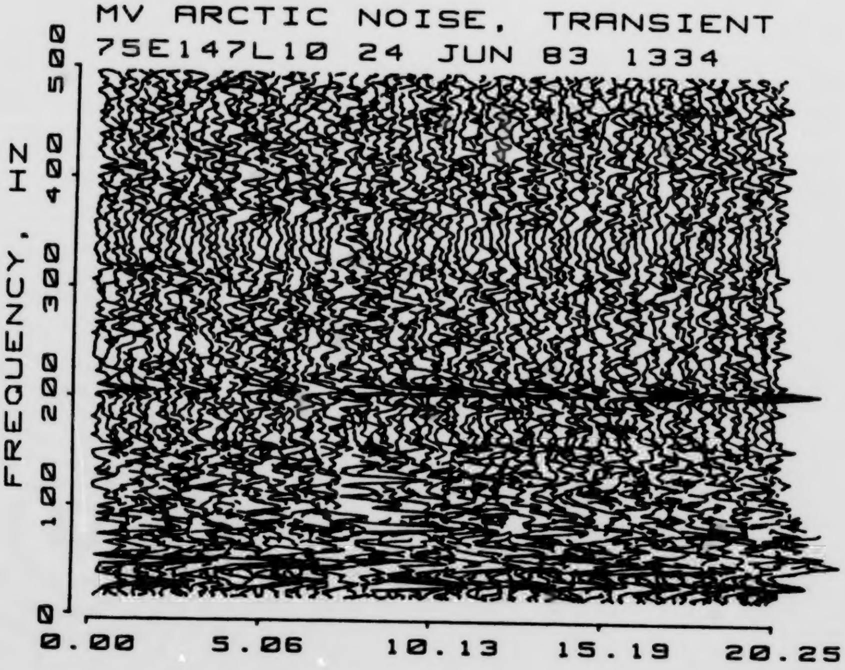


Fig. 21. Waterfall spectrograms for MV *Arctic* sounds at 20 m depth at range of 9.9 km (top) and 5 km (bottom).

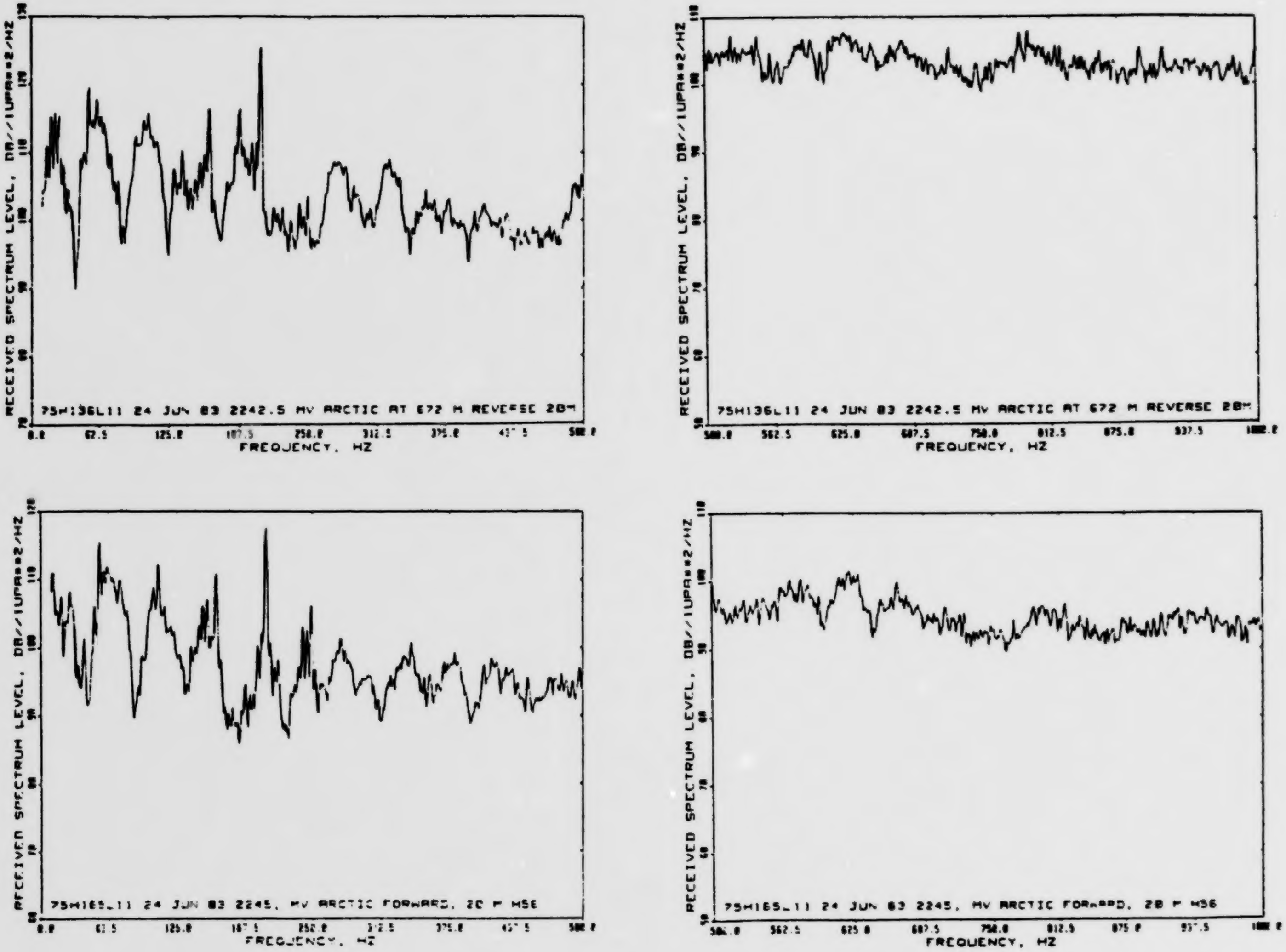


Fig. 22. Spectra for MV Arctic at range 672 m, in reverse at 22:42.5 and going ahead at 22:45, 24 June 1983.

Distribution and Numbers

Bad weather conditions prevented an aerial survey of the ice edge by helicopter on 24 June. Thus, we have no information on the patterns of distribution and numbers of animals along the ice edge on the day that the MV Arctic approached and entered the ice edge.

Whale Behaviour

Observers at the ice edge saw no whales between 06:00 and 08:30 on 24 June. At 08:33, four narwhals surfaced close to the ice edge and remained resting at the surface for 70 s before diving beneath the ice edge and moving northward. At 08:55, the observer (RH) again noted a group (thought to be the same group) about 100 m north of his position. These narwhals were lying close to the ice for at least a minute before they disappeared beneath the ice edge. At 08:56, a similar sized group appeared about 400 m to the north and remained close to the ice edge for about 2 min before submerging. Again at 09:06, they surfaced 200 m closer to the observer; they swam slowly and remained quietly at the surface before moving southward. Another group of 12 adult narwhals appeared close to the observer at 09:13. They remained at the surface for 110 s in very close formation--some touching--before disappearing beneath the ice edge. At 09:30 the observer noted a single narwhal 2 m from, and 'hugging' the ice edge. Between 09:35 and 09:41 nine belugas moved south very close to the ice edge. These observations were made by R. Hurst of DIAND who had limited previous experience with narwhal and beluga behaviour. Significantly, the behaviours he observed and described are similar to those observed along the Admiralty Inlet ice edge in June 1982 as the MV Arctic approached that edge (Finley et al. 1983:53).

The next observer (KJF) began observations at 09:45. After watching five groups of belugas (total of 14 whales) and two groups of narwhals (total of 3 and 4 males) moving close to and beneath the ice edge between 09:48 and 09:55, he became certain that their behaviour was abnormal and identical to the response shown to the approach of the Arctic on 28 June 1982 at Admiralty Inlet. Between 10:00 and 10:22, a total of 21 belugas passed the observer heading rapidly north undertaking long shallow dives beneath the ice edge. One group of seven belugas appeared from offshore, moving unusually rapidly, and disappeared beneath the ice edge. In marked contrast, the narwhals' movements were slow and they remained within a few metres of the ice edge, often lying quietly (i.e. their respirations were not audible) facing the ice edge in small, cohesive groups. Rather than diving in their normal manner, they tended to sink quietly beneath the surface. A total of 15 narwhals were seen between 10:30 and 11:37 but their general direction of movement could not be ascertained. None were seen after this. The last beluga was seen at 11:31 and its behaviour was notable in that it was moving south very slowly, remaining very close to the ice edge. A similar 'disoriented' behaviour was observed in 1982 when the ship neared the ice edge (Finley et al. 1983:52). The observer was unaware of the proximity of the Arctic, which was not expected until later in the day, and which entered the ice edge at 12:20 about 4-5 km to the south. At the time, a heavy snowfall limited visibility to <1 km.

Whereas the bulk of the rapid beluga movement was decidedly northward after 10:00, the direction of movement of narwhals was not clearly evident due to their habit of submerging and reappearing. The last whales seen before the ship's arrival were a female narwhal and a neonatal calf; they were moving south. Data on the distances of whales from the ice edge during this period demonstrate the close association ('hugging') of both species with the ice edge; 96% of the narwhals and 91% of the belugas were within 10 m of the ice edge (Fig. 15). By comparison, during the pre-disturbance period only 28% of the narwhals and 10% of the belugas were recorded <10 m from the ice edge. Most (65%) of the belugas that passed along the ice edge were females accompanied by immatures. Almost all (24 of 27) of the narwhals that could be positively classified were adult males in their typically cohesive pods.

Comparisons of the visible behaviour during this period with the pre-disturbance observations indicate that both belugas and narwhals were reacting to the ship when it was 45 to 60 km offshore from the ice edge.

Vocal Behaviour

Both narwhals and belugas were detected by the hydrophones at 06:00 on 24 June, although the weak signal strength indicated that they were not in the immediate vicinity of the recording station; they were not seen in the area at this time. By 08:00, the *Arctic* had become faintly audible on the hydrophones. At this time the whale calls had changed markedly. Harsh pulsive vocalizations were present. These are the calls (broadband screams) that were associated with an alarm response by belugas during the 1982 study. Another notable vocal component was the strong down-sweeping tonals illustrated in Figure 8. These calls and the harsh pulsive calls were also clearly audible at the satellite recording station located about 11 km away from the ice edge. It is assumed (see Discussion) that these 'alarm' calls were made by belugas, although no whales were actually observed at the ice edge until 1 h later when belugas were moving rapidly away from the area. The presumed alarm calls by belugas began when the *Arctic* was about 85 km from the ice edge.

The clicking sounds of narwhals were present but intermittent at 08:00; one series was unusual by its irregular short bursts but there was no evident change in the repetition rates and frequencies of the series that were analyzed spectrographically. Click series were not audible at the satellite recording station. The narwhal sounds were heard about 15 min prior to the visual observations in which we detected an apparent reaction to the ship.

Due to poor signal:noise ratio, we were unable to perform spectrographic analysis of the 10:00 recording. The ship noise was stronger and the vocal signals of the belugas seemed to recede during the recording session. Many of the calls were of the harsh pulsive type and apparently originated from the belugas that were rapidly transitting the area at that time. No identifiable narwhal sounds were heard although narwhals were present at the ice edge observation site. By 11:00 only a few faint tonal vocalizations of the belugas could be discerned. After 12:00 no other whale sounds were heard and ship noise predominated.

First Quiet Interval

(09:07 25 June to 07:58 26 June)

Ship Position and Ambient Noise Levels

The arrival of Arctic to the south of our camp on 24 June caused some local destabilization of the ice that endangered our camp. We were forced to move the camp from station 2 to station 3 on the south side of the ship track (see Fig. 1). This process took a considerable amount of time. Behavioural observations from the ice edge were not resumed until 16:00 on 25 June, although some measurements of ship noise were made away from the edge before this (see Fig. 4).

Except for a two hour period during the afternoon of 24 June, the Arctic operated continuously until 09:07 on 25 June when it shut down its engine and bubbler system. It had been ice-breaking during this period and was 14 km from our observation station (3) when it stopped (see Fig. 23). During the 'first quiet interval' the Arctic was idle with its engine off and propeller disengaged; some onboard machinery was operating.

There was no evidence of ship-related noise in our samples from this quiet interval. Three samples from the ice edge on 25 June (14:00, 20:00 and 24:00) were analyzed. At the 20 m hydrophone depth, ambient noise in the 20-1000 Hz band ranged from 97 to 102 dB//1 μPa. The ambient samples were dominated by narwhal and beluga calls. The levels were similar to those found during the pre-disturbance period (see Appendix A). Ambient levels at higher frequencies (1 and 16 kHz) were also similar during the pre-disturbance period and the 'first quiet interval' (Appendix B).

Distribution and Numbers

Two aerial surveys were flown on 25 June. These surveys were conducted 2 and 10 hours after the Arctic had ceased ice-breaking operations after nearly 21 h of continuous activity.

The first aerial survey on 25 June (beginning at 10:59) showed that narwhals had already returned to the disturbance area (Fig. 23A). In fact, two adult males were resting in the small bight that was created by the ship. A total of 95 narwhals were seen in the immediate area, most of them (53%) engaged in circling and diving movements. A small number (22) of narwhals were recorded along the two northern segments of the ice edge and these whales were moving south. These narwnals represented the first sightings along the northern part of the ice edge and offer some evidence of displacement from the southern sections of the ice edge, the only area that had been occupied during the pre-disturbance period. A total of 117 narwhals were recorded during the entire survey; the majority (80%) of those were adult males. Very similar numbers were present during the pre-disturbance period.

Belugas appeared to be just arriving at the northern edge of the disturbance zone, where 67 were counted; most (73%) were moving south. Large numbers (850) were encountered along the northern part (particularly the northern half) of the ice edge and almost all of them were moving south (Fig. 23A). A total of 1133 belugas was recorded on the entire survey.

The distribution of whales during the second survey of the day (begun at 19:24) indicates that whales may have continued moving south from the northern portion of the ice edge during the afternoon. A total of 872 belugas was recorded; they were fairly evenly distributed along the entire ice edge with 158 in the disturbance zone (Fig. 23B). The general movement of the belugas was still southward. Narwhals had moved out of the disturbance zone; they were found primarily along the central portion of the ice edge, where 56 were counted. The majority (80%) of these were resting at the surface.

In the absence of survey data from 24 June when the Arctic arrived, it is difficult to interpret the distribution patterns observed on 25 June. There is some circumstantial evidence that whales were displaced on 24 June and were returning on 25 June. Both belugas and narwhals were present in the disturbance zone about 2 h after the ship stopped operating--at a distance of about 14 km.

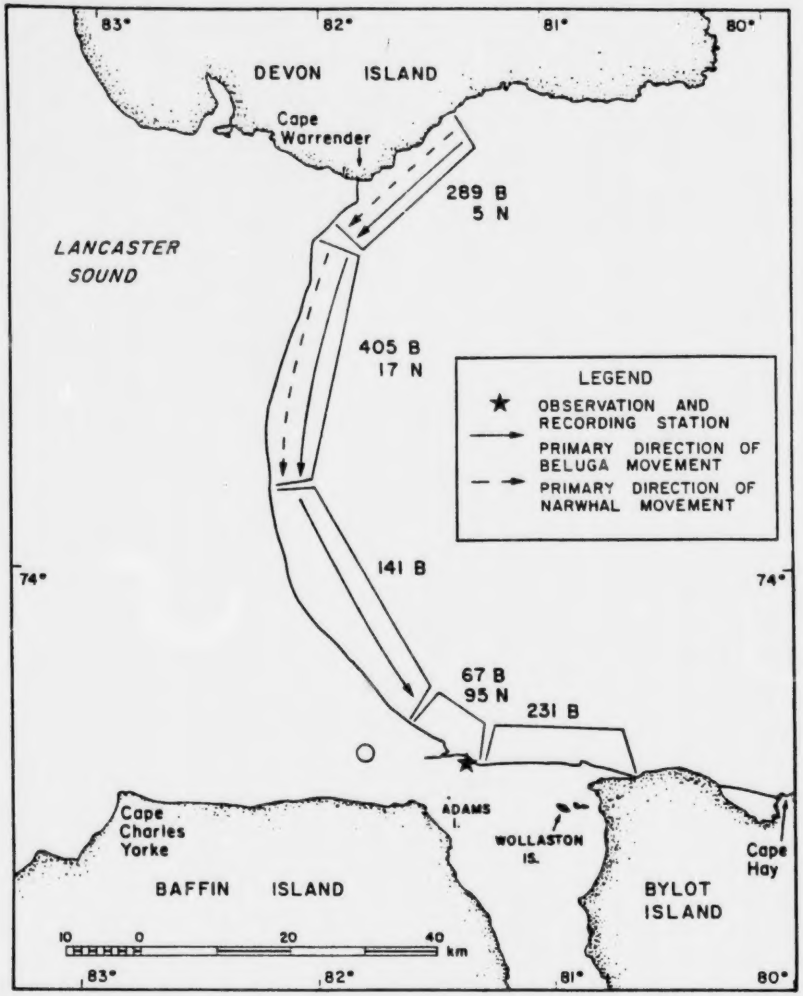
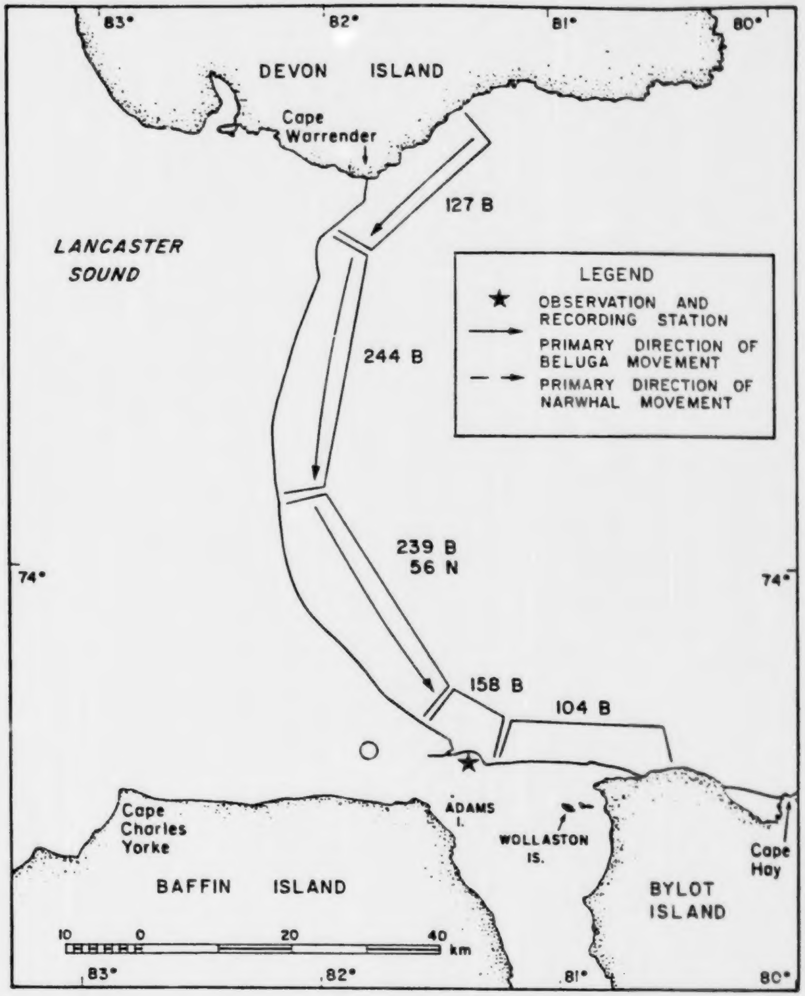

83°
82°
81°
80°
DEVON ISLAND
Cape Warrender
289 B
5 N
LANCASTER SOUND
405 B
17 N
LEGEND
★ OBSERVATION AND RECORDING STATION
PRIMARY DIRECTION OF BELUGA MOVEMENT
PRIMARY DIRECTION OF NARWHAL MOVEMENT
74°
141 B
74°
67 B
95 N
231 B
ADAMS I.
WOLLASTON IS.
Cape Charles Yorke
BAFFIN ISLAND
BYLOT ISLAND
Cape Hay
10
0
20
40
km
83°
82°
81°
80°

Fig. 23A. Distribution and numbers of narwhals and belugas recorded during survey 6, 10:59-11:49, 25 June 1983. Totals of 117 narwhals and 1133 belugas were recorded. The position of the MV Arctic at the time of the survey is indicated by an open circle.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DEVON ISLAND
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PRIMARY DIRECTION OF NARWHAL MOVEMENT
244 B
74°
239 B
56 N
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158 B
104 B
ADAMS I.
WOLLASTON IS.
Cape Charles Yorke
BAFFIN ISLAND
BYLOT ISLAND
Cape Hay
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80°

Fig. 23B. Distribution and numbers of narwhals and belugas recorded during survey 7, 19:24-20:24, 25 June 1983. Totals of 56 narwhals and 872 belugas were recorded. The position of the MV Arctic at the time of the survey is indicated by an open circle.

Whale Behaviour

Two teams of ice-based observers conducted watches during the 16 hour period from 16:00 on 25 June through 08:00 on 26 June. One team was located north of the ship track (near the camp vacated on 24 June) and the other was located south of the ship track.

Belugas were not seen in the immediate vicinity of the ship track until 18:00 when small numbers were first seen by the 'northern' observer; the whales were moving north quite strongly. The 'southern' observer first saw belugas at 20:00 arriving from the southeast. Small numbers of belugas continued to move along the ice edge throughout the night (Fig. 24). After midnight movements occurred in both directions, and many belugas dove beneath the ice. Measurements of the swimming speed of six different groups of belugas along a straight segment (400 m) of the ice edge ranged from 3.7-8.8 km/h ($\bar{x}$ = 6.4 km/h ± s.d. 2.0). A group of narwhals (two females and a neonatal calf) travelled at 5.3 km/h.

After 02:00 on 26 June, fewer belugas were exhibiting directed movements and more were circling and diving beneath the ice edge. Apparently they were feeding. 'Social' activity was also observed and included cases of fluke thrashing, body contact and chases, especially among the immature animals. Between midnight and 08:00, 203 of 324 (62%) belugas and 24 of 73 (33%) narwhals were engaged in circling/diving movements. During the previous 8 hour period only 6 of 96 (6%) belugas and none of the 4 narwhals were diving.

Both species of whales were less closely associated with the ice edge during this quiet interval than during the disturbance period (Fig. 15). However, the two species were somewhat more closely associated with the edge than during the pre-disturbance period.

The sex and age structures of the whales observed during the two aerial surveys and during the ice-based watches are shown in Figure 25. The ice-based watches yielded a slightly lower percentage of beluga females and immatures (32%) than did the aerial data (41%). Neither of these figures is significantly different from the pre-disturbance aerial survey data (38%). The majority (80%) of the narwhals were adult males.

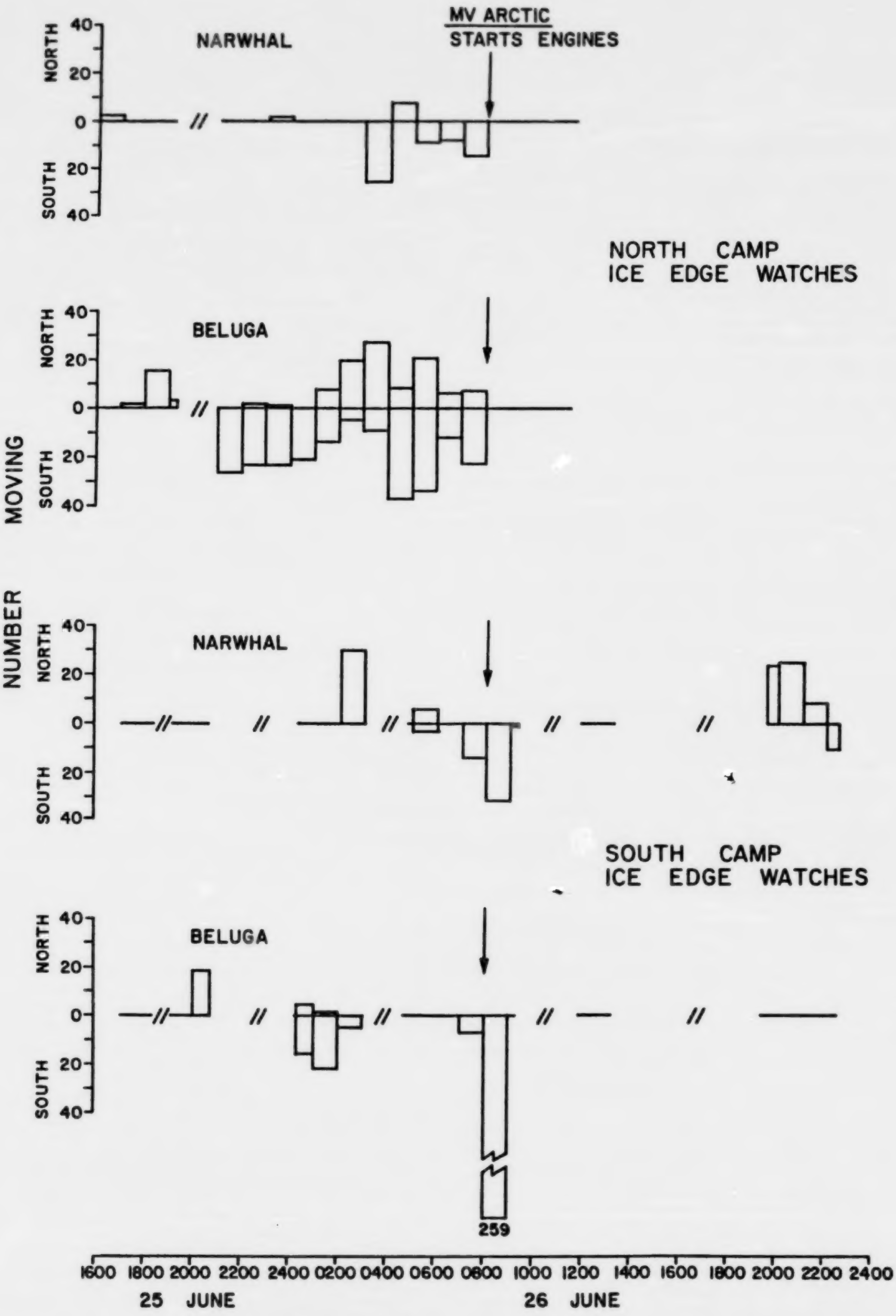


Fig. 24. Directional movements of narwhals and belugas recorded during ice-based watches at two camps before and after the start-up of the MV *Arctic* at 08:00 on 26 June 1983.

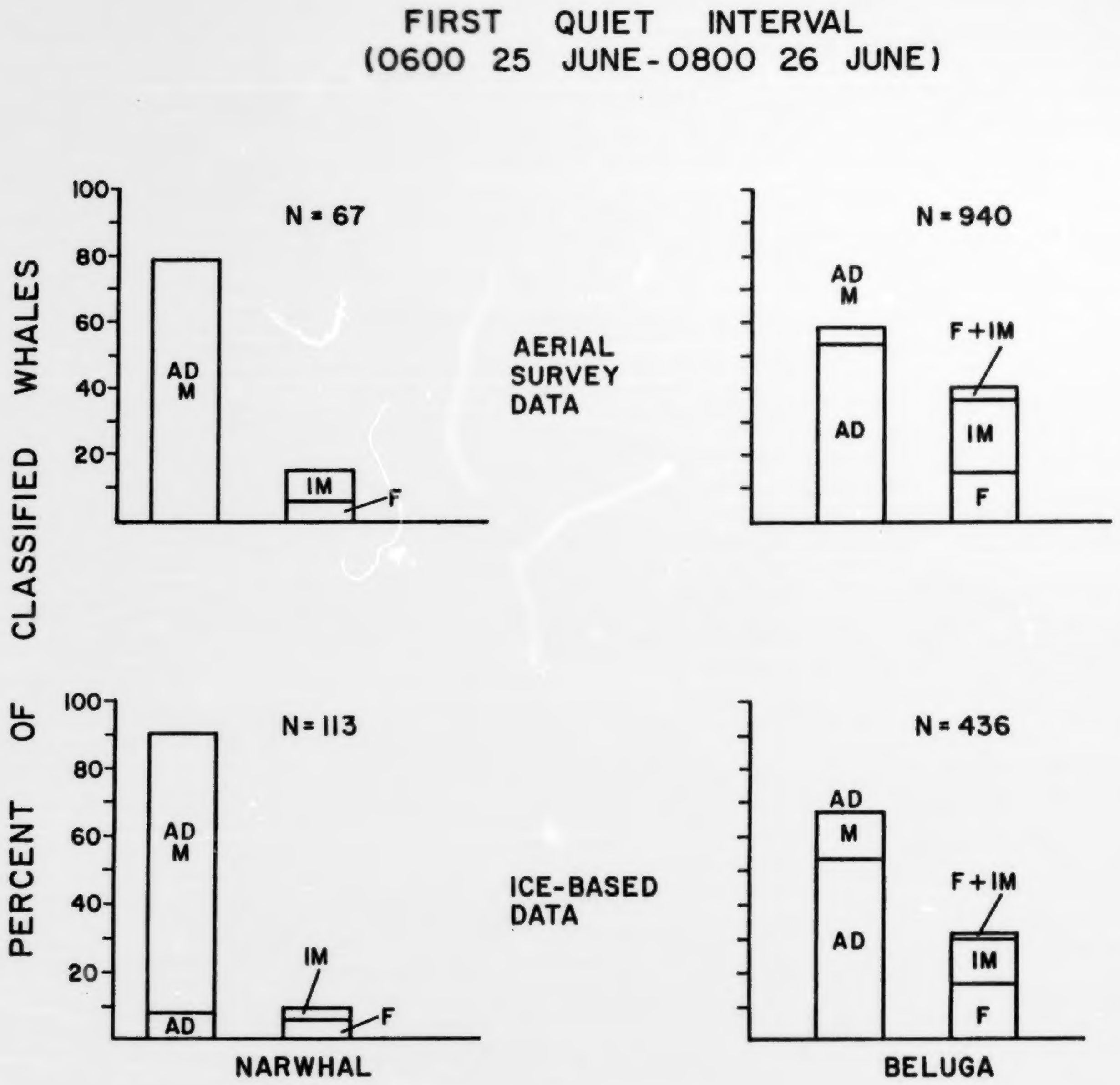


Fig. 25. Sex/age composition of narwhals and belugas recorded by aerial and ice-based observers during the first quiet interval.

Vocal Behaviour

Narwhals were present in the ship bight at the time of the first aerial survey at 11:00 (Fig. 23A). Their dense 'clatter' of click series was strong on the first recordings that were obtained at 14:00. Pulsed tones were absent in the 14:00 recording. Narwhal sounds receded by 16:00 as narwhals moved out of the area (see previous section); they were not heard again until 02:00 on 26 June when several returned to the area (Fig. 24).

Beluga tonals were only faintly audible at 14:00, but by 16:00 stronger tonals indicated that belugas had moved closer. Tonals remained few and indistinct during recording sessions until 22:00 when the tapes became saturated (24 calls per 30 s) with a wide variety of tonals, especially strong uptrilling calls (9 of 21 calls) and high buzzes (6 of 21 calls). Beluga tonals were present in the next 3 recording sessions ending at 04:00 on 26 June. Beluga behaviour appeared normal and undisturbed--many groups were circling and diving beneath the ice edge, apparently feeding. Their vocal repertoire contained a normal level of tonal calls (see later sections).

Second Disturbance Period
(07:58 26 June to 02:53 27 June)

Ship Positions and Received Noise Levels

Before 07:58 on 26 June, the MV *Arctic* had been idle about 14 km from the observation/recording station. At that time the ship started up and commenced ice-breaking. Received noise levels at the recording station reached 124 dB//1 μPa in the 20-1000 Hz band at 20 m depth. The *Arctic* continued breaking ice without much progress until 11:20 when it stopped to await assistance from the icebreaker CCGS *John A. MacDonald*. Received noise levels prior to shutdown of the *Arctic* varied between 114 and 121 dB//1 μPa but dropped to 93-99 dB//1 μPa in the 20-1000 Hz band at 20 m depth when *Arctic* stopped and the *MacDonald* was 70 km away. Noise levels at 13:15 when *MacDonald* was at a range of 23 km were 109 dB//1 μPa (20-1000 Hz band at 20 m). Between 14:18 and 14:30 noise levels from *MacDonald* varied between 113 and 121 dB//1 μPa as it attempted a short cut to the Arctic's track through the fast ice about 10 km north of the recording camp. After progressing <1 km in about 2 h, MacDonald backed out and entered the Arctic's track. Maximum received noise levels reached 125 dB//1 μPa at 16:55 as MacDonald moved through the ice rubble in Arctic's track at a distance of 2.8 km from the hydrophone (Fig. 26 presents spectra for this situation). Noise levels remained strong throughout the day as MacDonald continued to break ice westward (Appendix A). The ship sounds generally alternated between steady forward phases of 50-70 s duration and rumbling-rapping reverse phases of 105-125 s durations. At 18:20, when MacDonald was operating at a distance of about 13 km from the hydrophone, maximum noise levels of 122 dB//1 μPa were recorded during a reversing phase and 114 dB during a forward phase (20-1000 Hz band, at 20 m depth). These phases were usually separated by brief (5-10 s) relatively quiet (102-104 dB) periods. The MacDonald shut down at 02:53 on 27 June.

Whale Behaviour

During the hour prior to the start-up of Arctic at 07:58, observers on both sides of the ship track saw a total of 31 narwhals. Only the northern observer saw belugas (36). Except for 7 belugas, all whales were reported as moving south and a few were engaged in circling movements and dives directed beneath the ice.

The responses of belugas to the start-up of the Arctic were soon evident to the two ice-based observers, especially the one located on the south side of the ship track. Neither was aware of the ship's start-up but at 08:08, the southern observer noted the beginning of a large rapid movement of belugas (adults and immatures) along the ice edge eastward from the ship track. Over 225 belugas passed by within 9 min in a continuous herd. The belugas were moving very rapidly, diving was asynchronous, and pod integrity had broken down. On two occasions, calves fell behind adults by as much as 3 m, suggesting difficulty in maintaining the rapid pace. Dives were shallow, close to or beneath the ice edge, and the heads came unusually high out of the water during surfacing/respiring. The end of this rapid movement occurred at 08:39. The observer on the north side of the ship track saw only

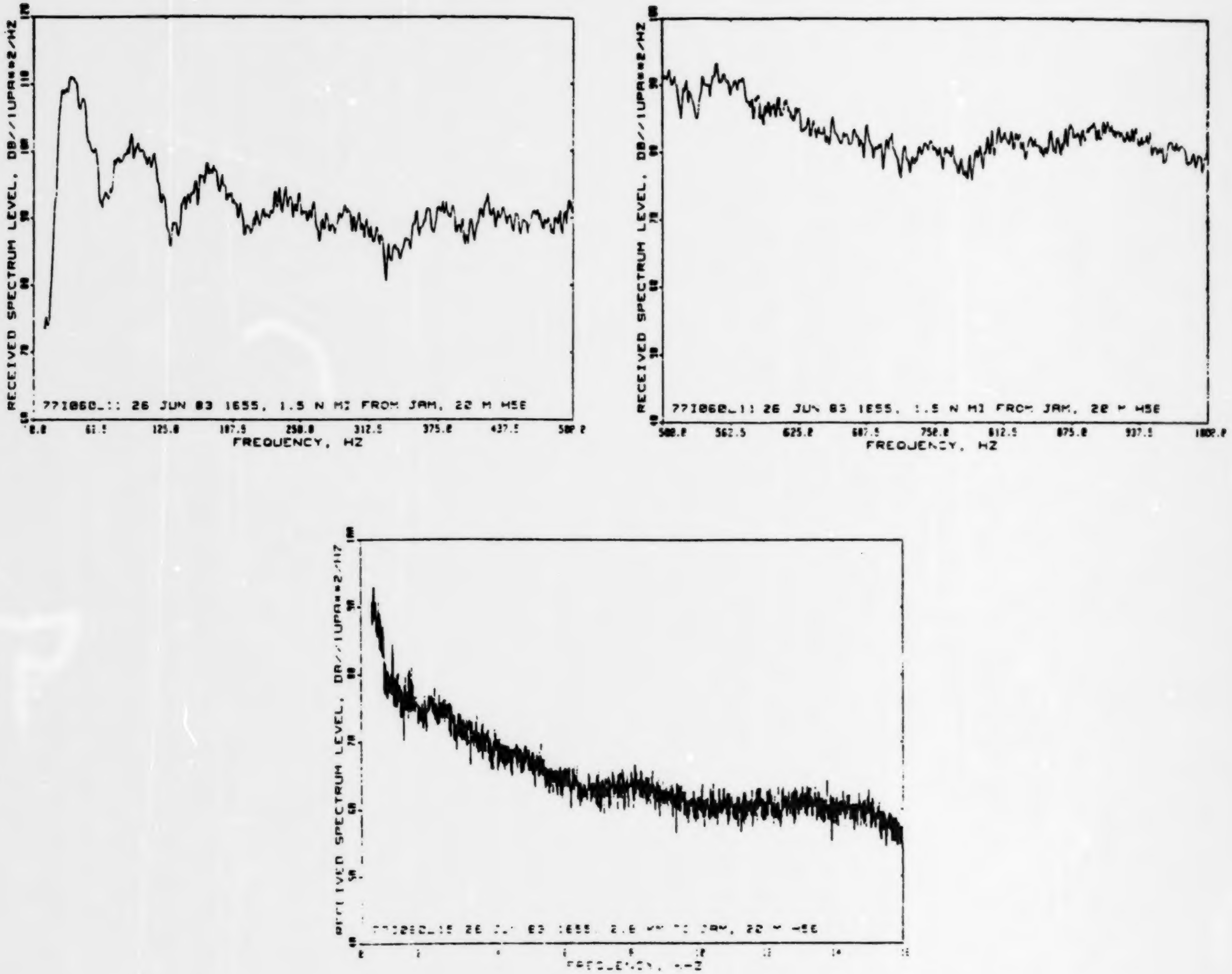


Fig. 26. Spectra from the icebreaker CCGS John A. MacDonald at range 2.8 km, 16:55 on 26 June 1983. Hydrophone depth is 20 m.

one beluga after ship start-up; it surfaced from beneath the ice 2 min after start-up and was moving south. The beluga behaviour in apparent response to the ship was clearly recognizable as the same panic reaction that was observed in the 1982 study. During this movement, most (>80%) of the belugas were within 10 m of the ice edge (Fig. 15).

The southern observer saw 6 pods of adult narwhals (total of 28) plus 4 individual narwhals during the period of rapid beluga movement after 08:00. He noted that most of them were moving rapidly south close to the ice edge except that one group of three was lying within 3 m of the ice edge. The last whale seen in the area was a narwhal seen at 09:09. The northern observer did not see any narwhals after the ship start-up. Narwhals were not as closely associated with the ice edge during this period as they were during the approach of the Arctic during the 'first disturbance' (Fig. 15).

Vocal Behaviour

When our 10-min recording session began at 08:00 (2 min after start-up of the Arctic), received noise levels were high--up to 124 dB//1 µPa in the 20-1000 Hz band. The strong noise initially masked many of the whale sounds, although several pulsed screams (= alarm calls) were heard over the ship noise during the first 5 min of recording. Spectrographic analyses of sounds recorded during the first brief lull in the ship noise revealed only long trains of rapid chirps. By 08:05 other beluga tonals were barely audible and none was audible after 08:15. This underwater record corresponded closely with the rapid movement of belugas that was first seen at 08:08 by the observer on the south side of the ship track. Only one click series from a narwhal was heard after 08:00.

Distribution and Numbers

Two aerial surveys were conducted on 26 June. The first survey began at 09:22 about 1.5 h after start-up of the Arctic. The second survey began at 14:28 about 1 h after the MacDonald reached the vicinity of the ice edge about 10 km north of our station.

The first survey documented a strong northward movement of belugas and narwhals along the ice edge. Virtually all whales north of the ship track were moving north. The southmost of the northbound whales were seen at 09:52, when we first encountered narwhals 22 km north of the ship track. No belugas were recorded until 10:04, approximately 49 km north of the ship track (Fig. 27A).

About 1100 northbound belugas were counted, but this figure is probably imprecise because the animals were usually tightly grouped and were moving rapidly, undertaking long dives beneath the ice edge. All animals, when not actually beneath the ice edge, were less than about 20 m from the ice edge. The narwhals (66) did not appear to be moving at more than a 'casual' pace and were mostly trailing the belugas.

Although the ice-based observer on the south side of the ship track had observed a 'panic' movement of over 200 belugas in response to the start-up of Arctic, the continuation of this movement was not evident to the aerial observers after 09:30. Belugas (393) and narwhals (129) along the Navy Board ice edge were not showing any strongly directed movements (Fig. 27A). Many were circling and diving beneath the ice edge close to the coast of Bylot Island.

The afternoon survey, which began at 14:28 after MacDonald had entered the ice edge, showed that the belugas had continued their movements and were concentrated at the extreme ends of the ice edge along the coasts of Devon and Bylot islands (Fig. 27B). More than 1000 belugas were found near the Devon Island coast; some were still moving north along the adjacent ice edge. The closest belugas were 80 km north of the ship track. There was a marked absence of whales around the ship track. About 1200 belugas were seen near the Bylot coast and many were moving strongly to the east along the coast near Cape Hay, about 30 km east of the ship bight, at 15:15. By 15:20, it was noted that the main body of belugas had reversed direction and were moving back toward the ice edge.

Narwhals (total of 31) were first seen about 37 km north of the ship track during the afternoon survey. Only 9 were moving north while the others were either resting at the surface or circling and diving. One narwhal was

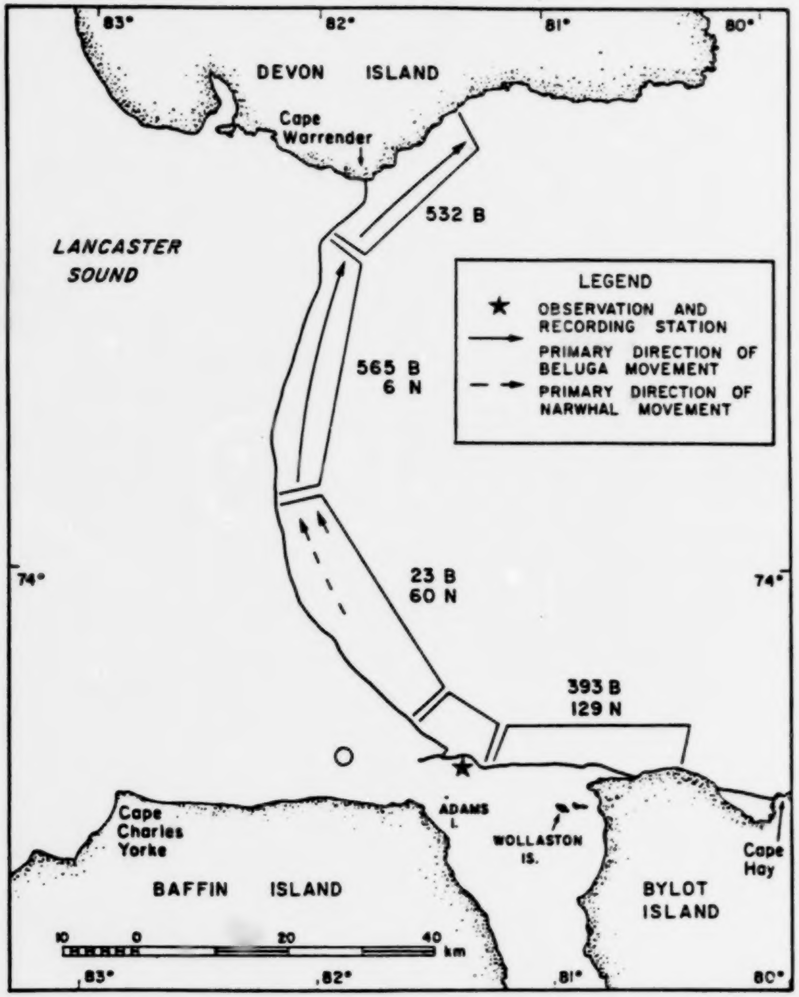
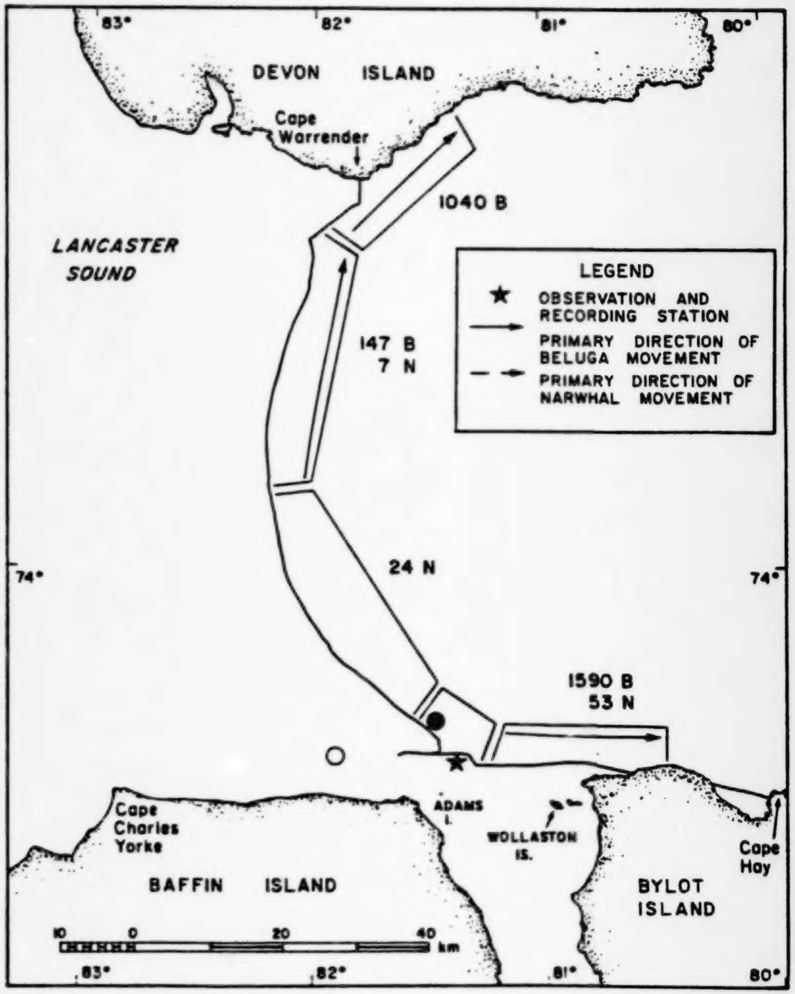

83°
82°
81°
80°
DEVON ISLAND
Cape Warrender
532 B
LANCASTER SOUND
LEGEND
★ OBSERVATION AND RECORDING STATION
PRIMARY DIRECTION OF BELUGA MOVEMENT
PRIMARY DIRECTION OF NARWHAL MOVEMENT
565 B
6 N
74°
23 B
60 N
74°
393 B
129 N
ADAMS I.
WOLLASTON IS.
Cape Charles Yorke
BAFFIN ISLAND
BYLOT ISLAND
Cape Hay
10
0
20
40
km
83°
82°
81°
80°

Fig. 27A. Distribution and numbers of narwhals and belugas recorded during survey 8, 09:22-10:57, 26 June 1983. Totals of 195 narwhals and 1513 belugas were recorded. The position of the MV Arctic at the time of the survey is indicated by an open circle.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DEVON ISLAND
Cape Warrender
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LANCASTER SOUND
LEGEND
★ OBSERVATION AND RECORDING STATION
PRIMARY DIRECTION OF BELUGA MOVEMENT
PRIMARY DIRECTION OF NARWHAL MOVEMENT
147 B
7 N
74°
24 N
74°
1590 B
53 N
ADAMS I.
WOLLASTON IS.
Cape Charles Yorke
BAFFIN ISLAND
BYLOT ISLAND
Cape Hay
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km
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82°
81°
80°

Fig. 27B. Distribution and numbers of narwhals and belugas recorded during survey 9, 14:28-16:50, 26 June 1983. Totals of 84 narwhals and 2777 belugas were recorded. The position of the MV Arctic and CCGS John A. MacDonald at the time of the survey are indicated by open and solid circles, respectively.

observed moving offshore. The apparent reduction (by 50%) in numbers along the ice edge relative to numbers seen during the morning survey suggests that some animals had moved offshore. Fewer narwhals were also seen along the Navy Board ice edge than had been seen during the morning survey. By contrast, over 1000 more belugas were seen along the ice edge near the Bylot coast than had been seen during the morning surveys. Possibly these animals had arrived from offshore or from the east.

Return of Narwhals

Belugas were not seen or heard throughout the second disturbance period. However, narwhals were present in the disturbance area at 19:30 when ice-based observations resumed. At this time the MacDonald was breaking ice at a distance of 13 km. Received noise levels at 20:00 were 120 dB//1 μPa in the 20-1000 Hz band at 20 m depth. During quieter intervals, a few narwhal click series were audible. A total of 73 narwhals were seen between 19:30 and 22:30; the majority (85%) were involved in directed movement to the north although three were reported as resting and another was circling/diving. At 21:00 the received noise level was 118 dB//1 μPa (20-1000 Hz band at 20 m) as MacDonald was backing at a distance of 19 km. In the quieter intervals narwhal click 'clatter' was strong. A few pulsed calls (2 per 30 s) were also heard. Narwhal 'clatter' continued until midnight but was absent at 02:20 about 0.5 h before the MacDonald shut down.

Second Quiet Interval
(02:58 to 07:32 27 June)

The second quiet interval consisted of a brief 4.5 h period when both ships were shut down. No observations were made during this period because of the instability of the ice. During the night a large piece of ice broke from the ship track leaving a larger embayment or 'bight' with the ship track at its apex (see Fig. 28). Recording sessions at 04:00, 05:00 and 07:00 all contained narwhal click series. The sounds of ice cracking were especially notable at 04:00, and strong narwhal 'clatter' was heard at 05:00 and 07:00. Pulsed calls were infrequent or absent in all sessions. Beluga tonals were infrequent and often barely audible above the background ambient (94 dB//1 μPa in the 20-1000 Hz band at 20 m depth) at 07:02.

Third Disturbance Period
(07:32 27 June to 02:24 28 June)

Ship Positions and Received Noise Levels

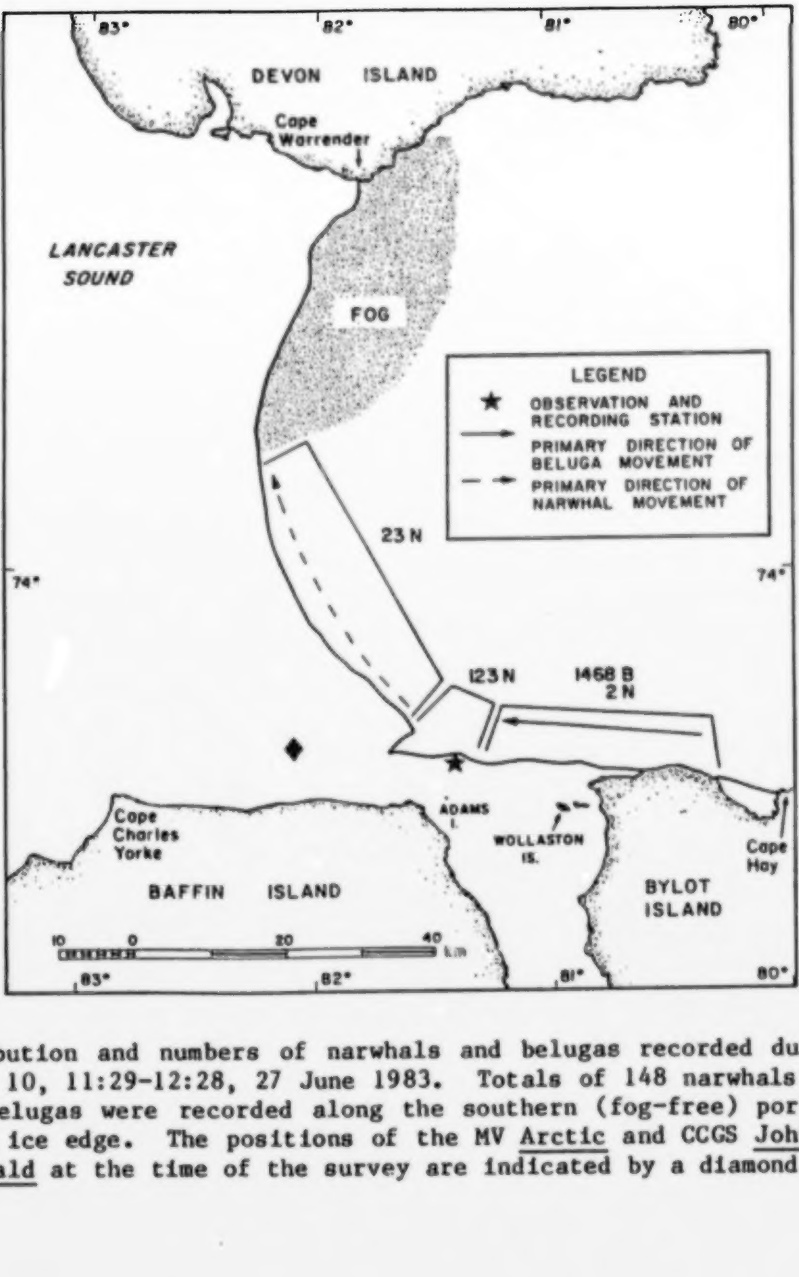
The MacDonald resumed ice-breaking operations at 07:32 on 27 June. It proceeded slowly westward throughout the day stopping periodically to conduct sound transmission tests (Greene in prep.). The MacDonald shut down for the night at 02:24 on 28 June. The Arctic remained stopped throughout this period.

The received noise levels from the MacDonald at a distance of 24 km ranged from 109 to 114 dB//1 µPa in the 20-1000 Hz band at 20 m depth when the ship was in the backing phase of its 'backing-and-ramming' ice-breaking cycle. Received levels were 101-103 dB//1 µPa in the forward mode. Because of the large ice sheet that was loosened (and dispersed) by the icebreaker activity, it was necessary to move our camp from location 3 (Fig. 1) at the mouth of the bight to location 4 (Fig. 2) at the head of the bight. Received ship noise levels ranged from 106 to 115 dB//1 µPa (20-1000 Hz band) at 18:20 when the ship was 20 km distant (see Appendix A). Noise levels remained intermittently strong (to 116 dB//1 µPa) until the MacDonald shut down for the night at a distance of 23 km.

Distribution and Numbers

The aerial survey flown on 27 June began at 11:29, 4 h after the start-up of the MacDonald. Good coverage was obtained of the southern and eastern portions of the ice edge but fog prevented completion of the northern portion of the survey. Weather and visibility conditions along the southern and eastern portions of the ice edge were excellent.

Almost all narwhals (123) were found in the newly-created bight in the ice (Fig. 28). Many were resting on the surface and several were diving beneath the ice edge, particularly in the vicinity of the ship track. A total of 23 narwhals were counted along the ice edge north of the ship track and only 2 were found along the Navy Board ice edge where 53 had been seen on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DEVON ISLAND
Cape Warrender
LANCASTER SOUND
FOG
LEGEND
OBSERVATION AND RECORDING STATION
PRIMARY DIRECTION OF BELUGA MOVEMENT
PRIMARY DIRECTION OF NARWHAL MOVEMENT
23 N
74°
74°
123 N
1468 B
2 N
ADAMS I.
WOLLASTON IS.
Cape Charles Yorke
BAFFIN ISLAND
BYLOT ISLAND
Cape Hay
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40
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83°
82°
81°
80°

Fig. 28. Distribution and numbers of narwhals and belugas recorded during survey 10, 11:29-12:28, 27 June 1983. Totals of 148 narwhals and 1468 belugas were recorded along the southern (fog-free) portion of the ice edge. The positions of the MV Arctic and CCGS John A. MacDonald at the time of the survey are indicated by a diamond.

the previous evening. Thus there appeared to have been a movement of narwhals from the eastern end of the ice edge into the bight.

A large number (1500) of belugas were found along the Bylot Island coast where about the same number (1600) had been seen the evening before. As was the case during the previous survey, no belugas were recorded along the portion of the ice edge where the ships had entered the ice, and none were occupying the ice edge segment immediately to the north of that disturbance zone. Segments farther to the north could not be surveyed, but the general distribution observed on the portions of the ice edge that could be surveyed were so similar to those observed the previous evening that it seems safe to assume that large numbers of belugas remained far to the north.

Whale Behaviour

Ice-based observations began at 11:00 from the position of camp 3 which, due to ice movement, was then situated at the mouth of the ship bight. Observations were conducted from this position until 16:00 but only three groups (5, 2 and 2) of narwhals were observed; they were moving westward into the ship bight. A distinctively marked adult male narwhal remained near the observer for over 3 h. The narwhal undertook 11 dives between 12:42 and 16:04 ranging from 6-35 min in duration (mean = 16 min) with surface times of 1.8-3.2 min (with the exception of one 8 min surfacing). Respiration rates at each surfacing ranged from 8.1-9.4/min. The MacDonald was operating at a range of about 25 km during this period.

Observations of narwhal behaviour were continued from 16:55 onward at the head of the bight (Camp 4-Fig. 2). This area was the focus of much diving activity. Diving continued unabated until after midnight. Almost all of the distinctive deep dives (flukes up) occurred within 50 m of the ship track and were directed toward the rubble-filled track. Many animals also surfaced in the ship track entrance but it appeared that many animals surfaced undetected elsewhere; for example, in a 2 h period between 18:00 and 20:00, a total of 117 narwhals initiated deep dives into the track but only 85 surfaced in the track. Surfacing animals generally rested for several minutes before turning and slowly moving toward the ship track. Deep dives were usually preceded by 2-3 short shallow dives followed by a strong exhalation and, finally, the typical deep dive posture. Many individuals were marked by distinctive scars and were recognized several times between 17:00 and midnight; however, due to the amount of diving activity and the orientation of the animals, we were never absolutely certain of the dive times of individually marked animals. Our impression was that many dives were about 10-15 min long. At any one time there were about 11-15 narwhals (maximum of 21) resting on the surface and diving activity was steady.

On several occasions, as the narwhals closely approached the ship track, we were able to observe their underwater movements clearly within 10 m of the ship track. One interesting activity that we often noted among narwhals just at or slightly beneath the surface was that they swung the anterior portion of their bodies back and forth in a sweeping manner (arc approximately 20°) with their bodies oriented about 10-20° downward from the surface. This sweeping behaviour usually occurred prior to the animals undertaking deep dives. Since many strong click series were heard during this period, it is possible that the narwhals were echo-scanning under the ice.

Although we were unable to provide a quantitative evaluation of individual diving behaviour, it did not appear that the diving activity was influenced by the MacDonald which was operating intermittently at a distance of about 20 km. For example, during a quiet period between 17:26 and 17:58, a total of 36 narwhals initiated deep dives into the ship track and in the following 34 min period when the ship was operating, a total of 41 initiated deep dives into the ship track. Of five recognizable individuals observed in the quiet period, four were again observed during the subsequent noisy period.

Vocal Behaviour

The underwater recording session at 07:00 was saturated with narwhal 'clatter' and some distant beluga tonals. At 09:07, 1.5 h after start-up of the MacDonald , and in the quieter intervals between ramming and backing, narwhal 'clatter' was unabated and pulsed calls were frequent (8 per 30 s of spectrographic analysis). A few beluga tonals and a single pulsed scream were barely audible at the beginning (09:00) of the recording session.

Narwhal 'clatter' and pulsed calls were present in recordings taken throughout the day as the MacDonald was ice-breaking at a distance of 20 to 23 km from the apex of the ship bight. After 14:00 the recording camp was moved to the apex of the ship bight and at 17:24 the first recordings were obtained of narwhals diving in the ship track. Noise from the MacDonald was intermittently strong (to 115 dB//1 μPa). Narwhal click 'clatter' and pulsed calls saturated the quieter intervals and appeared normal in frequency and repetition rates. At 17:26 MacDonald shut down during sound tests and remained quiet until 17:58 when it started up strongly. During the first brief quiet interval 30 s after start-up we did not detect any click 'clatter' or pulsed tones but after 50 s, click series resumed and a few strong series remained audible as ship noise again peaked at 115 dB. The number of pulsed calls remained similar before (8 per 30 s) and after (6 per 30 s) start up. During this start-up period narwhals (about 21 males) continued actively diving at the entrance to the ship track with no apparent change in behaviour (see previous section). It appeared that the number of pulsed calls was associated with the level of diving activity; the maximum level of pulsed tones (21 per 30 s) was recorded just following a period (5 min) when 12 adult male narwhals had undertaken deep dives.

Belugas were not heard after 09:00 on 27 June until about 18:45 when a few distant tonals indicated that some were approaching. The first group of about five belugas arrived at the ship track at 20:30 during a short period (20:10-20:55) when MacDonald was quiet. At 20:35 the recordings were saturated with a variety of sounds (such as grunts and squeals) as this group of belugas closely investigated the hydrophones. Strong echolocation bursts were heard. About 20 narwhals were also diving in the area at the time and we cannot be certain of the origin of the echolocation sounds. However, their coincidence with the arrival of the belugas and other typical beluga sounds strongly suggested that the belugas were responsible. (Indeed, although we had been recording almost continuously for the previous 3 h we did not hear any echolocation pulses directed at the hydrophones from the many narwhals that were diving close to the hydrophones.)

No other belugas approached the ship track until 22:11 when an adult and a neonatal calf dove under the ship track amongst about 25 narwhals. Another 2 or 3 groups of belugas (total of about 12 individuals) were seen in the immediate area during the next hour. At 23:30 large numbers of belugas were seen moving northward across the mouth of the ship bight to the ice edge proper. The movement appeared strong and directed but due to the distance it was not possible to determine the numbers of whales involved. At 23:55 the MacDonald, which had been quiet since 23:15, started up. Maximum received noise levels achieved 116 dB//1 μPa in the 20-1000 Hz band at 20 m depth. This elicited a notable change in beluga vocalizations during the 30 s analysis; pulsed screams (9), buzzes (5), falling tonals (9) and rapid chirp trains (3) became predominant. These signals seemed to recede during the 10-min recording. At 01:00, the ice edge observer noted that the "beluga movement appears to have stopped" (KJF field notes). Although this anecdote is imprecise, it suggests that the apparent alarm response may have originated from the belugas that were transitting the area during the short quiet interval. Narwhals remained diving in the ship track and, as in the previous start-up at 17:58, we did not discern any change in their click and pulsed tone emissions.

Third Quiet Interval
(02:24 to 08:15 28 June)

Both ships remained stopped in the ice from 02:24 to 08:15 on 28 June. Due to poor weather conditions and unstable ice, observations were not conducted between 02:00 and 06:00, although underwater recordings at 04:00 indicated that only a few narwhals were in the area. At 06:00 many tonal vocalizations indicated that belugas were in the area; about 40-50 animals were observed diving at the entrance to the ship track. Visibility was poor due to strong winds, snow and a high sea state. After 07:00, the belugas appeared to move east out of the area; 23 animals were seen up until 07:58 and none were observed afterward.

Fourth Disturbance Period

(08:15 to 19:44 28 June)

Ship Positions and Received Noise Levels

The *MacDonald* began operations at 08:15, 23 km from the recording station, and finished 11.5 h later after breaking a track 5 km long. Maximum received noise levels reached 115 dB//1 µPa (20-1000 Hz band at 20 m) during backing operations soon after start up. Typically the strongest sounds were the rapping/ rumbling sounds associated with backing operations and the lowest sounds occurred during steady forward phases (Greene in prep.). The *Arctic* began operating at 10:30, 10 km from the recording station, and proceeded along *MacDonald's* track throughout the day. At noon the received noise levels, with both ships operating, ranged between 113 and 116 dB//1 µPa in the 20-1000 Hz band at 20 m depth (see Appendix A).

Whale Behaviour

Strong onshore winds prevailed throughout the day and visibility was limited by snow showers, high seas and breaking ice. Several belugas were seen amongst ice pans about 15 min prior to the start up of the *MacDonald*; the observer reported that there appeared to be an eastward movement of belugas before the start up. It is possible that the belugas moved out of the area in response to some unknown pre-start-up activity of the *MacDonald* but due to the poor visibility it is unlikely that the observer would have noticed any overt reactions.

Vocal Behaviour

Only a few distant tonal vocalizations could be heard over the strong ambient noise (102 dB) at 08:10, just prior to the ship's start-up. A single high buzz call immediately followed the start-up at 08:15 and several indistinct pulsive sounds were heard following the next two sessions of stronger ship noise during backing. No whales were observed throughout the day and no whale vocalizations were heard until 20:00, 15 min after the *MacDonald* shut down for the day. At this time, a few narwhals were moving into the area as was evident by their click 'clatter'. Very few pulsed calls were heard from these animals and none were detected in 30 s of spectrographic analysis that was saturated with click series. It is uncertain whether the absence of whales throughout the day was due to disturbance by the ships or whether it was caused by the influence of high sea states.

Fourth Quiet Interval

(19:44 28 June to 05:58 29 June)

A few narwhals began appearing off the ship track at 20:11, 25 min after MacDonald had shut down. Sea state was Beaufort 3 and about 200 m of pan ice beset the ship track and ice edge. The first arriving narwhals were moving slowly in heavy seas just beyond the margin of pack ice. Click clatter predominated in the underwater recordings. Very few pulsed calls were heard.

After 23:00, the strong onshore wind began to subside and the pack ice began to disperse. Adult male narwhals began appearing in the calmer interstices almost immediately and often rested, nearly motionless, for several minutes before submerging or undertaking deep dives. The following information on the respiration rates of four different individuals was obtained.

Table 3. Respiration rates of narwhals occupying the ship bight during the Fourth Quiet Interval.

Previous activity	Blow intervals (s)
resting	8 9 9 9 8 7 7, submerges for 16 s, then blows and deep dives. Mean blow interval = 8.1 ± 0.9
surfaces	6 7 5 5 8, submerges for 32 s, then surfaces 5 6 6 6 6 7 6 5, submerges 8, then blows and deep dives mean blow interval = 6.0 ± 0.9
surfaces	8 7 8 8 7 9 8 8 8 10 8 9 8 9 8 10 8 9 9 9 10 13 9 8 10 10 9 10 7, submerges mean blow interval = 8.8 ± 1.2
surfaces	7 7 8 9 7 8 7 7 6 7, deep dives mean blow interval = 7.3 ± 0.8

The range of respiration rates (6.8 to 10.0/min) gives some idea of the level of physiological activity of undisturbed resting narwhals. The fastest rate was from an individual that appeared to have just arrived in the area; the others had been resting prior to our examination.

Around midnight there were about 10 narwhals resting and deep diving near the ship track. Their click clatter dominated the noise spectra and pulsed calls had increased notably (to 8 in 30 s). Several 'swallowed gulps' in close association with strong pulsed calls of nearby animals made us certain that, on this occasion, these sounds originated from the narwhal; the 'swallowed gulp' sounds were aurally and spectrographically indistinguishable from a similar sound produced by belugas. Only four tonal calls were heard in the 10-min recording session and none were detected on the 30 s spectrographic analysis. The high signal to noise ratio during the recording session indicated the close proximity of the narwhals to the hydrophone. Again, as in previous recordings in close proximity to diving narwhals, we did not detect any strong pulsing investigation of the hydrophones as was usually the case when belugas were present. Narwhals were apparently not attracted to the hydrophones (as belugas often were).

The first belugas appeared in the ship bight at 02:00, about 6 h after the MacDonald shut down. Several remained in the area, many of them undertaking dives under the ship track, throughout the remainder of the fourth quiet interval. Most of the narwhals withdrew from the vicinity of the entrance to the ship track after the arrival of the belugas. However, narwhals remained in the area, as was evident from their dense click clatter at 02:00 and 04:00. Visibility was limited to <1-2 km in snow showers during this period but the observers could hear the 'bellows' of narwhals somewhere farther offshore in the ship bight. Beluga tonals were present but not especially numerous (despite their proximity) in the recording sessions at 02:00 (6 calls/30 s) and 04:00 (11 calls/30 s). Their calls encompassed a normal array of uncomplicated tonals (e.g., linear and rising tonals). No uptrilling calls were heard.

Fifth Disturbance Period
(05:58 to 23:00 29 June)

Ship Positions and Received Noise Levels

The MacDonald started operations at 05:58, 28 km west of the recording station. When it stopped for the day at 23:00, it was 6 km farther west. Maximum received noise levels following start-up reached 112 dB//1 μPa (20-1000 Hz band at 20 m depth). At 09:30, the Arctic began moving west toward the MacDonald but became stuck in the track. Between 10:00 and 11:00 the MacDonald returned eastward along its track and between 11:00 and 12:00 it broke ice to release the Arctic. Received noise levels reached 121 dB//1 μPa in the 20-1000 Hz band with both ships operating at a distance of 18-20 km. At 22:56, just before MacDonald shut down for the day, maximum received noise levels were 111 dB (see Appendices A and B).

Whale Behaviour and Distribution

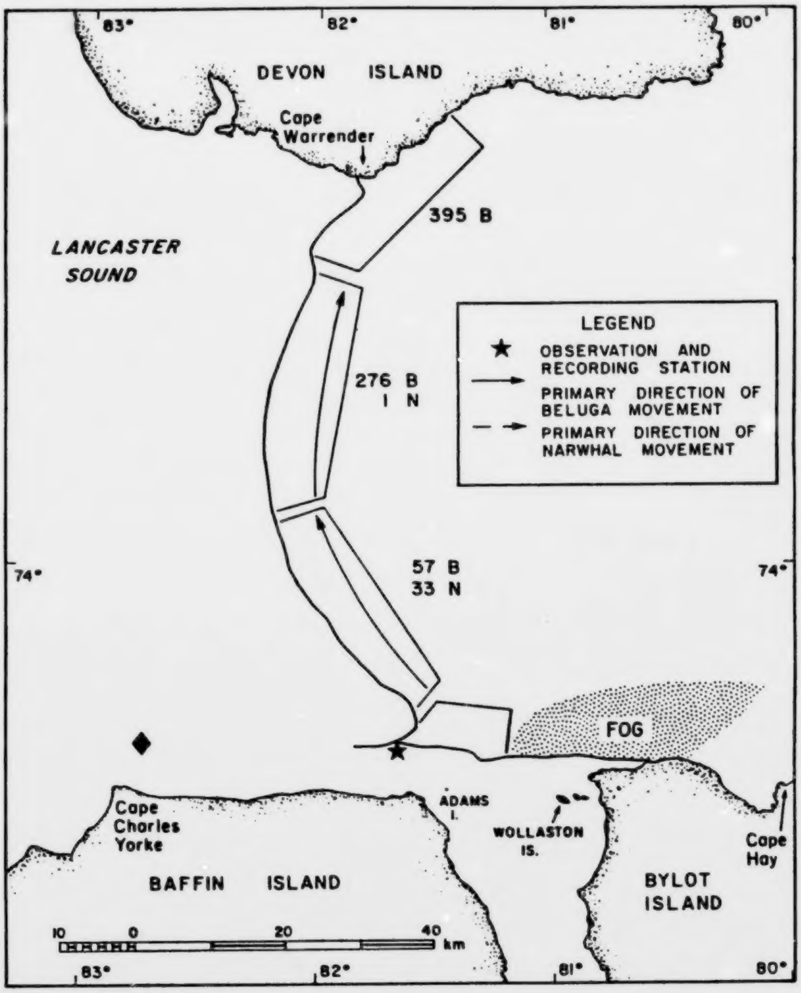
In the hour preceding the start up, several small groups of belugas arrived from the east and were diving and surfacing near the ship track. These animals departed north along the ice edge when the ship started. None was seen during the hour after 06:02. No narwhals were seen in the hour prior to the ship start up and they were not audible in the recording session at 05:58. Beluga signals were the only biological sounds audible on the tapes when the ship started. The calls included several pulsed screams (= alarm calls, 4 in 30 s), longer trains of morse tonals (5 in 30 s), irregular undulating tonals (3 in 30 s), and a variety of other tonal vocalizations. It was the impression of the listener that the strongest ship sounds elicited more pulsed screams and rapidly repeated tonal series but this could not be analyzed spectrographically due to signal overload.

Belugas and narwhals returned to the entrance to the ship track 1.3 h after MacDonald's start up; vocal activity by both was strong in the recording session at 08:00. Visibility was limited by snow showers and pack ice at the time and it was not possible to ascertain the numbers of each species in the area. Not more than about 6-7 animals of each species were in view at any one time. Ship noise levels were intermittently strong and did not elicit any pulsed 'alarm' calls from the belugas. Most beluga sounds were rapid, long chirp series (4 per 30 s) and uptrills (6 per 30 s). Many grunts and squeals were heard from belugas that were closely investigating the hydrophone with nearly continuous echo-investigating pulses during the 08:00 recording session. Narwhal click series were present but were not dense during this recording session or again at 10:00. Beluga tonals were again dominant in the 10:00 session (along with intermittent ship noise) but the recording contained a normal component of linear (10 in 30 s), uprising (3 in 30 s), and undulating (2 in 30 s) tonals.

During the period when the MacDonald returned toward the ice edge to free the Arctic, both belugas and narwhals left the area. The last belugas (11) were seen moving north between 10:51 and 10:58. Between 10:00 and 11:13, a total of 14 narwhals were recorded moving south or resting; none were seen thereafter. By 12:00 only distant beluga tonals were heard.

An aerial survey begun at 15:43 showed that narwhals and belugas were absent from the bight but both species were found along the ice edge just to the north (Fig. 29). The southern segment of the ice edge was not surveyed due to fog. A total of 34 narwhals and 673 belugas were recorded north of the ship bight. Most (80%) belugas in the two ice-edge segments immediately north of the ship bight were moving north during the survey although 20% were resting or diving beneath the ice edge. No strongly directed movements were seen in the belugas along the northernmost sector of the ice edge. Narwhals along the middle sections of the ice edge did not show any marked movement--most were resting at the surface.

After the Arctic was released around noon, both ships returned westward and noise levels faded somewhat. The whales remained away from the disturbance area until 20:00 when the first narwhals returned and 21:00 when a few belugas were seen. Received noise levels from the ships at 20:00 were 110 dB in the 20-1000 Hz band. By 21:00, about 45 narwhals were in the area of the bight, many undertaking deep dives or resting at the surface. The underwater record was saturated with their dense clatter of click series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DEVON ISLAND
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33 N
74°
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ADAMS I.
WOLLASTON IS.
Cape Charles Yorke
BAFFIN ISLAND
BYLOT ISLAND
Cape Hay
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Fig. 29. Distribution and numbers of narwhals and belugas recorded during survey 11, 15:43-16:55, 29 June 1983. Totals of 34 narwhals and 728 belugas were recorded along the four northern ice edge segments. Fog prevented a survey of the southeastern ice edge segment. The positions of the MV Arctic and CCGS John A. MacDonald at the time of the survey are indicated by a diamond.

along with frequent (14/30 s) pulsed calls. Only a few belugas appeared in the area before MacDonald shut down for the night.

Fifth Quiet Interval
(22:30 29 June to 05:00 30 June)

Narwhals remained in the vicinity of the bight throughout this quiet period; many of them were undertaking deep dives into the ship track or resting and socializing in scattered pods. Various levels of activity occurred on an intermittent basis; at first most animals were engaged in diving activity into the entrance to the ship track but around 01:00 this activity ceased and the narwhals (virtually all males) coalesced into pods that were either resting quietly or engaged in considerable social activity. The most obvious above-water interaction was tusk crossing involving 2-5 individuals; as many as 4 groups were involved in this activity at any one time. By 02:15 this activity had nearly ceased and 35 were narwhals resting quietly on the surface of the bay; these motionless animals were drifting offshore with the current.

Narwhal click clatter and pulsed calls were dominant in the recordings throughout this quiet period. Pulsed calls were especially numerous (17 in 30 s) during a period (22:30) of intense diving and noticeably less numerous (5-6 in 30 s) during resting behaviour. Ambient noise levels at 02:27 (with considerable input from dense click clatter) were 96 dB//1 µPa in the 20-1000 Hz band at 20 m depth.

Very few belugas appeared in the area until late in this quiet period. At 05:30 there were about 30 belugas, nearly all adults, many of them diving into the ship track entrance. Beluga tonals were present in all recordings taken in this quiet period but were especially strong at 04:00 as a few individuals were diving in the area. As usual, belugas were attracted to the hydrophones which were under near-continuous echo-investigation. Many strong grunts and squeals accompanied the echo-locating sounds. As well, the session at 04:00 was notable for strong uptrilling calls (6 in 30 s) along with a full range of regular tonal signals.

Sixth Disturbance Period
(05:55 to 22:10 30 June)

Ship Positions and Received Noise Levels

The MacDonald began operations at 05:55 about 36 km west of the recording station and travelled about 5 km through the fast ice before it shut down for the night. The Arctic operated intermittently to move west to MacDonald's position. Maximum received noise levels were 116 dB//1 μPa in the 20-1000 Hz band during backing operations, but levels were generally lower (101-105 dB) or inaudible during other operations.

Whale Behaviour

No strong responses by belugas or narwhals were noted at the start up of the MacDonald at 05:55. At 05:45 there were 30 belugas and 5 narwhals swimming and diving in the ship track and at 06:15 there were 25 belugas and 10 narwhals in the same area. Belugas were present (max. 30 at any one time) throughout the remainder of the day as one or both ships continued breaking ice at a distance of 36 to 41 km. Narwhals remained (max. 9) around the ship track for 2 h after the ship start up but were not seen between 08:30 and 20:00, after which a few appeared.

Vocal Behaviour

Although the ice-based observer did not note any unusual surface behaviour of belugas and narwhals in response to the ship start up, the sound record indicated a vocal response by the belugas, especially to the stronger (to 116 dB//1 μPa in 20-1000 Hz band) sounds during backing. For example, a strong backing sound of the ship at 06:05 elicited a total of 7 pulsed buzzes in 30 s along with nearly continuous series of sequential chirps (8 in 30 s). A minute later during a quieter moment no pulsive sounds or chirps were heard and the signals included many regular tonal sounds along with bouts of echo-investigation of the hydrophone. The sound levels received from the belugas faded during this recording session as the animals apparently moved away from the ship track. Although narwhals were present (as many as 10) during the 06:00 recording session, they were apparently quiet as no clicking sounds or pulsed calls were detected.

Beluga sounds were predominant during all 10-min recording sessions throughout the remainder of this disturbance period. There was no apparent influence of the ship noise on their vocalizations even though the ship noise level occasionally reached 116 dB during backing (about 106 dB during steady forward operation). During many of the recording sessions belugas were diving at the entrance to the ship track. They also spent considerable time investigating the hydrophones with echolocation. During these close encounters they uttered many grunt and squeal sounds. Their sounds also included a wide array of linear (12/30 s), undulating (6/30 s) and various accented (6/30 s) calls. Narwhal clicks were inaudible throughout most of the day until 20:00 when a few animals appeared and the normal background click clatter resumed.

Distribution and Numbers

A partial aerial survey was flown between 12:42 and 13:45 on 30 June as the MacDonald was intermittently operating at a distance of 40 km. At this time belugas were scattered in small numbers (3/km) in the ship bight and along adjacent areas of the ice edge southeastward to Cape Hay (Fig. 30A). No narwhals were seen in the bight or along the adjacent ice edge but a dense concentration of about 50 narwhals along with 400 belugas was found and photographed along the Navy Board Inlet ice edge, north of Wollaston Islands. Many of the animals were diving into a small embayment on the ice edge. Several large herds of harp seals were also present along with large numbers of foraging seabirds. Such multi-species aggregations usually indicate intense feeding activity on arctic cod (Boreogadus saida) (Finley and Gibb 1982). It was apparent that whale movements along adjacent parts of the ice edge were directed toward the activity site, although some belugas were also dispersing offshore from the aggregation.

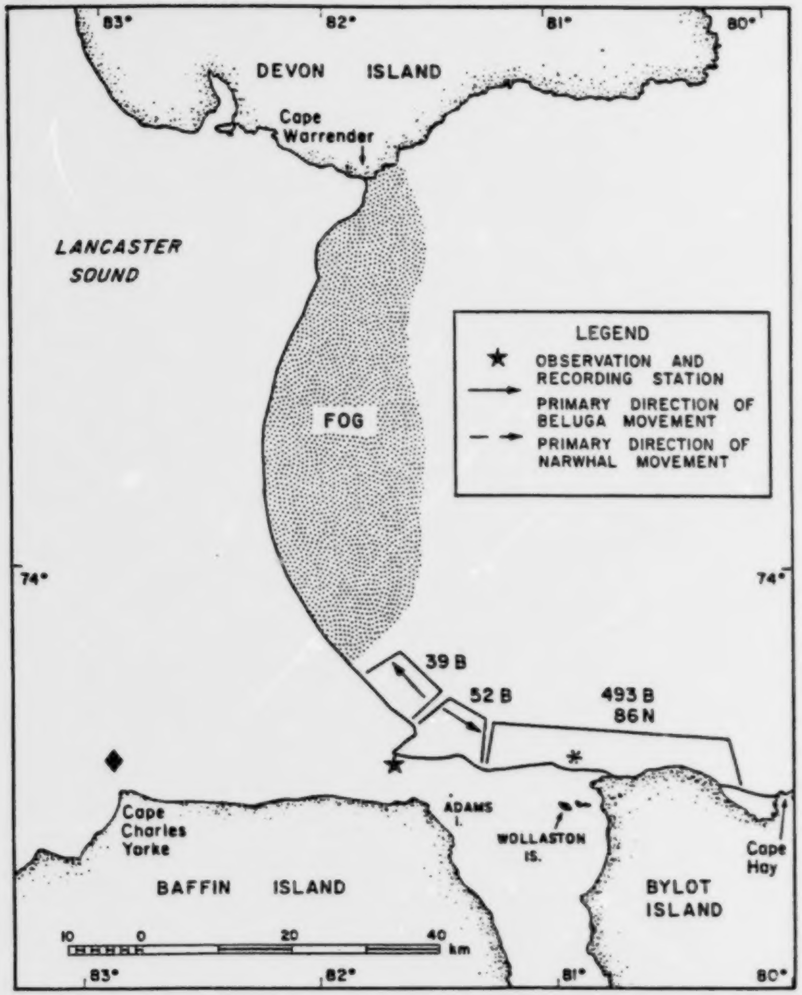

83°
82°
81°
80°
DEVON ISLAND
Cape Warrender
LANCASTER SOUND
FOG
LEGEND
OBSERVATION AND RECORDING STATION
PRIMARY DIRECTION OF BELUGA MOVEMENT
PRIMARY DIRECTION OF NARWHAL MOVEMENT
74°
74°
39 B
52 B
493 B
86 N
Cape Charles Yorke
ADAMS I.
WOLLASTON IS.
Cape Hay
BAFFIN ISLAND
BYLOT ISLAND
10
0
20
40
km
83°
82°
81°
80°

Fig. 30A. Distribution and numbers of narwhals and belugas recorded during survey 12, 12:42-13:45, 30 June 1983. Totals of 86 narwhals and 584 belugas were recorded along the southern (fog-free) portion of the ice edge. The asterisk represents the location along the Navy Board Inlet ice edge of an aggregation of 55 narwhals and 396 belugas. The positions of the MV *Arctic* and CCGS *John A. MacDonald* at the time of the survey are indicated by a diamond.

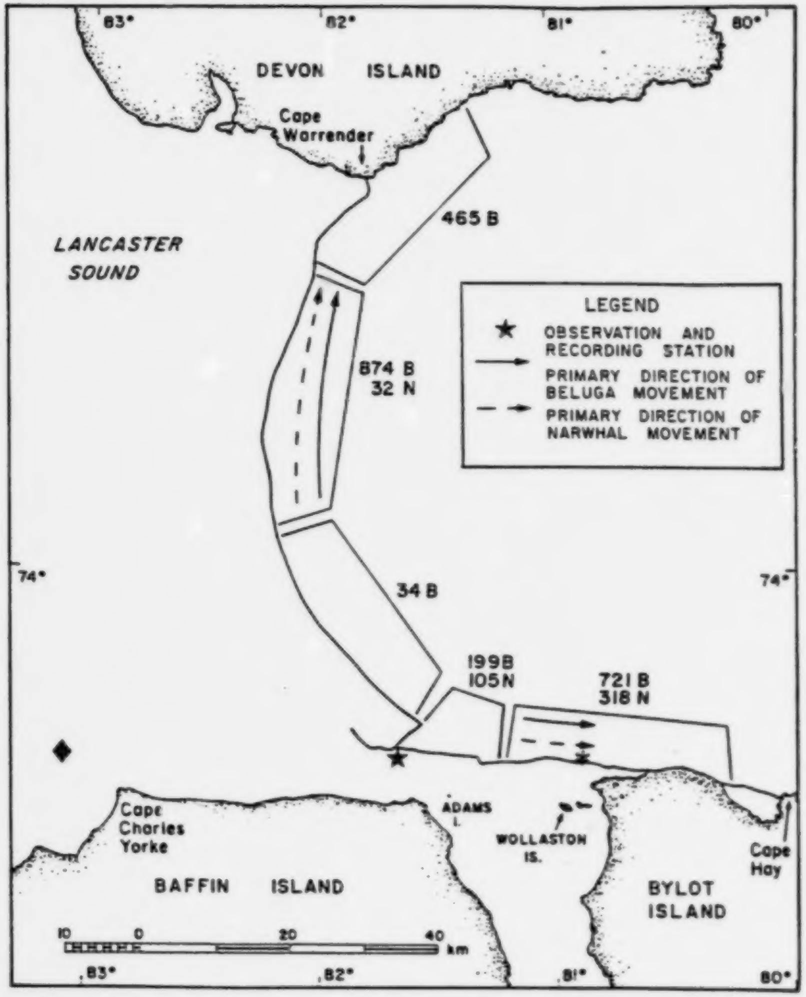

83°
82°
81°
80°
DEVON ISLAND
Cape Warrender
LANCASTER SOUND
465 B
LEGEND
OBSERVATION AND RECORDING STATION
PRIMARY DIRECTION OF BELUGA MOVEMENT
PRIMARY DIRECTION OF NARWHAL MOVEMENT
874 B
32 N
74°
74°
34 B
199 B
105 N
721 B
318 N
Cape Charles Yorke
ADAMS I.
WOLLASTON IS.
Cape Hay
BAFFIN ISLAND
BYLOT ISLAND
10
0
20
40
km
83°
82°
81°
80°

Fig. 30B. Distribution and numbers of narwhals and belugas recorded during survey 13, 12:35-14:25, 1 July 1983. Totals of 455 narwhals and 2293 belugas were recorded. The asterisk represents the location along the Navy Board Inlet ice edge of an aggregation of 239 narwhals and 391 belugas. The positions of the MV *Arctic* and the CCGS *John A. MacDonald* at the time of the survey are indicated by a diamond.

Sixth Quiet Interval
(23:50 30 June to 07:01 1 July)

There was not much whale activity during this quiet period. Although both narwhals and belugas were present throughout this period, they appeared in small numbers and appeared to be moving casually through the area, generally in a northerly direction across the mouth of the bight. A few narwhals directed dives under the ship track but they did not remain in the area. Around midnight, one individual male with a distinctive bullet scar was recognized from a previous encounter at 18:30 on 27 June. Two other individuals were also tentatively recognized from previous encounters during the evening of 27 June.

Both narwhal and beluga vocalizations were audible in all recorded segments during this period. Narwhal click clatter and pulsed calls predominated while beluga tonals tended to be fewer and more distant.

Seventh Disturbance Period
(07:01 1 July to 04:10 2 July)

Ship Positions and Received Noise Levels

During this period, one or both of the ships was operating near the mouth of Admiralty Inlet at distances of 41-49 km from the ice edge. The Arctic began operations at 16:40 and late in the day took over ice-breaking operations from the MacDonald. Ship noise was intermittently strong (to 113-115 dB//1 µPa in the 20-1000 Hz band at 20 m depth) during backing phases and strong forward phases (106 dB) but often faded to be nearly inaudible (especially against a strong acoustic input by whales) during steady ice-breaking modes.

Whale Behaviour

No narwhals and only 7 belugas were seen in the ship bight during the hour preceding MacDonald's start-up at 07:01, and no overt reactions were seen. Narwhals arrived at 08:38 and both species were present in small numbers (usually <10 at any one time, max. of 28 narwhals and 17 belugas) throughout the remainder of this period as the ships laboured between 41 and 49 km away. Occasionally narwhals and, less frequently, belugas, undertook dives into the entrance to the ship track.

A distinctly-marked adult male narwhal was recognized at 15:40 from a previous encounter on the evening of 27 June. This animal was resighted again at 04:30 on 2 July. This, and other resightings, provide evidence that narwhals exposed to earlier disturbances still returned to the same area of the ice edge (Table 4). The resightings also suggest that the adult male population of narwhals observed during this period along the ice edge was more or less stable (i.e. there was limited interchange with offshore animals). This suggestion is also supported by the relative constancy of numbers and sex composition of narwhals observed along the southern portion of the ice edge up until this time.

Table 4. Resightings of distinctively marked narwhals near Camp 4.

First Sighting	Second Sighting	Third Sighting
27 June--evening	1 July--15:40	2 July--04:30
27 June--18:30	1 July--00:00	-
27 June--evening	1 July--early a.m.*	-
27 June--evening	1 July--early a.m.*	-

* Indicates probable resighting.

Vocal Behaviour

Although we were not recording during the start-up of the *MacDonald* at 07:01, we did not discern any influence of ship noise on the vocal behaviour of narwhals or belugas throughout the remainder of the seventh disturbance period. Except for the session at 08:00 when both species had moved away from the ship track (they were still audible), both species were strongly vociferous in all recording sessions throughout the remainder of the disturbance period. On several occasions belugas closely investigated the hydrophones with strong echolocation pulses accompanied by the usual indecipherable cacophony.

Distribution and Numbers

An aerial survey was conducted between 12:34 and 13:52 on 1 July (Fig. 30B). Conditions were excellent throughout the survey with a low sea state (Beaufort 1-2), good lighting and unlimited visibility. As during the previous survey, a large mixed aggregation of narwhals and belugas was occupying a portion of the Navy Board Inlet ice edge, just north of the Wollaston Islands. Analysis of a series of photographs of the aggregation resulted in counts of 391 belugas, 239 narwhals, 44 submerged (unidentified) whales and 45 harp seals. Belugas and narwhals recorded along this ice edge segment that were not in the (presumed) feeding aggregation were moving strongly east toward the concentration.

Narwhals (105) and belugas (199) were recorded in the ship bight by aerial observers about six hours after the start up (at 07:01) of the MacDonald. An additional 1373 belugas were well distributed along the ice edge north of the ship bight, and 32 narwhals were recorded along the northern half of the thin perforated ice somewhat farther north than they were usually found. Totals of 2293 belugas and 455 narwhals were recorded during the survey. The narwhal total was notably higher than the previous high count of 195 narwhals recorded on the morning of 26 June.

Comparison of Whale Vocalizations During Disturbance and Non-Disturbance Periods

Changing ice conditions and the presence of Inuit hunters after 1 July prevented further comparisons of whale behaviour during disturbed and undisturbed conditions. Observations made after 1 July are presented in later sections of the report but first we compare the vocal behaviour of narwhals and belugas during disturbance and non-disturbance periods up to 1 July.

The vocalizations of belugas and/or narwhals were detected in 84% of the recording sessions when the ships were operating (disturbance periods), whereas they were audible in all recording sessions in the intervening quiet periods and in the pre-disturbance period. However, judging from received signal strengths, belugas were present within the immediate vicinity of the recording site during only 34% of the disturbance sessions and narwhals in only 50% of these sessions; this compares with 56% and 76%, respectively, in the intervening quiet periods and 57% and 70%, respectively, in the pre-disturbance period. This simple index of vocal activity is consistent with observations that show a greater sensitivity of belugas to disturbance and their tendency to remain away from the disturbance areas longer than the narwhal following disturbances.

Narwhal

Except for three occasions when narwhals ceased producing click emissions and pulsed calls during the initial phases of disturbance, there was no evidence that they changed the type or structure of their signals in response to ship noise. Pulsed calls accompanied click 'clatter' in 68% of 25 spectrographic segments during disturbance periods, in 71% of 14 spectrographic segments in the intervening quiet periods, and in 80% of 20 segments in the pre-disturbance period. The average number of pulsed calls per 30 s was similar in disturbance periods (5.2 ± s.d 5.8), quiet intervals (4.2 ± s.d. 4.0) and pre-disturbance periods (3.8 ± s.d. 3.9). The somewhat higher number of pulsed calls during the disturbance periods and intervening quiet intervals is probably due to the recording station being in the bight which was the focus of much diving activity by narwhals. There was no evidence of any change in the frequency emphasis or duration of pulsed calls in response to ship noise; the average lowest frequency (2.1 kHz ± s.d. 1.1) and highest frequency (2.7 kHz ± s.d. 1.0) during disturbance periods were similar to the results during quiet periods (2.0 ± s.d. 1.0 to 2.6 ± s.d. 1.2). The average signal duration was 0.9 s ± s.d. 0.6 during disturbance periods and 0.8 ± s.d. 0.4 during quiet periods.

As with pulsed calls, there was no evidence that ship noise had any effect on the click emissions of narwhals (at least those below 12 kHz). The average frequency of click series during noisy periods (4.4 kHz ± s.d. 1.7) was the same as that during quiet periods (4.4. kHz ± s.d. 1.9). Repetition rates were also similar (5.7/s ± s.d. 2.4 vs. 5.4/s ± s.d. 2.6, respectively).

Beluga

The frequency of occurrence and characteristics of various vocalizations used by belugas during periods of ship activity (= noisy periods) and during quiet periods are given in Table 5.

During undisturbed periods along the Lancaster Sound ice edge, the vocal repertoire of the beluga consisted of roughly 40% level, 25% shifted, 20% sweep frequency, and 12% structured tonals. Only one pulsed sound, the buzz, was heard during quiet periods, and it was heard in the context of excitement (see following section).

The most notable change in the beluga repertoire during disturbance periods was a shift to more pulsed sounds; during such periods they comprised about 14% of the repertoire. Two types of pulsed screams, the broadband scream and the tonal scream were unique to these periods (Table 5). Both of these pulsed screams were also recorded during the disturbance period in 1982 (Finley et al. 1983). Virtually all broadband screams and tonal screams were heard as initial responses to ship noise. Another notable component of the repertoire during disturbance was the increased number of down sweeping tonals (from 2% in quiet periods to 11%); these were heard in 46% of the disturbance segments analyzed but only 19% of the quiet periods (Table 5). Chirp trains were also heard more frequently (70% of disturbance segments) during disturbance periods and constituted about 12% of the disturbance repertoire. Some calls such as the distinctive uptrill and upward-inflected and stepped tonals were notably less common during disturbance periods compared with quiet periods (Table 5).

In addition to changes in call types in response to disturbance, belugas also altered the frequency emphasis or duration of some of their social signals in apparent response to disturbance. For example, during disturbance periods, undulating tonals covered a wider frequency range beginning at lower frequencies than during quiet periods (2.5 kHz ± s.d. 1.0 vs. 5.0 ± 2.9,

Table 5. Frequency of occurrence and characteristics of various beluga vocalizations from spectrographic analysis during disturbance and non-disturbance periods at the Lancaster Sound ice edge, June-July 1983.

Call type	% Occurrence[1]		% Composition		$\bar{x}$ Initial/Lowest Frequency[2] kHz ± s.d. (n)		$\bar{x}$ Final/Highest Frequency kHz ± s.d.		$\bar{x}$ Signal Duration (s)	
	in quiet periods (n = 31 segments)	in noisy periods (n = 26 segments)	in quiet periods (n = 356 calls)	in noisy periods (n = 396 calls)	in quiet periods	in noisy periods	in quiet periods	in noisy periods	in quiet periods	in noisy periods
Tonal Sounds										
Level										
constant	68	62	19	11	3.8 ± 2.4 (47)	4.5 ± 2.6 (29)	-	-	0.5 ± 0.5	0.5 ± 0.3
broken	48	50	10	13	4.8 ± 2.8 (25)	3.7 ± 2.2 (32)	-	-	0.7 ± 0.4	1.1 ± 0.7*
stepped	52	19	10	1	2.9 ± 1.7 (11)	2.9 ± 1.9 (7)	3.4 ± 1.8	2.9 ± 1.3	0.8 ± 0.5	0.8 ± 0.5
Shifted										
falling	19	46	2	11	5.4 ± 2.9 (7)	4.3 ± 2.4 (18)	4.1 ± 2.7	3.0 ± 2.4	0.5 ± 0.2	1.0 ± 0.4*
rising	32	23	3	2	3.8 ± 2.4 (11)	2.4 ± 1.0 (7)	4.6 ± 3.8	4.4 ± 1.1	0.7 ± 0.4	0.7 ± 0.1
inflected down	16	15	2	<1	7.9 ± 3.3 (4)	-	7.0 ± 4.5	-	0.7 ± 0.2	-
inflected up	26	4	6	1	4.7 ± 2.9 (20)	3.2 ± 1.1 (5)	4.8 ± 3.1	3.5 ± 1.1	0.6 ± 0.3	0.4 ± 0.2
undulating regular	26	30	5	4	5.0 ± 2.9 (16)	2.5 ± 1.0 (16)*	5.8 ± 3.6	4.8 ± 3.9	0.8 ± 0.4	0.9 ± 0.4
undulating irregular	23	54	6	8	2.6 ± 1.5 (22)	3.4 ± 2.0 (31)	3.4 ± 2.1	5.0 ± 3.5	0.9 ± 0.3	1.0 ± 0.3
Structured	4	3	12	11	2.6 ± 0.5 (15)	2.8 ± 2.2 (8)	5.2 ± 0.8	5.5 ± 3.7	0.7 ± 0.3	0.8 ± 0.3
Sweep Frequency										
chirps	32	30	10	6	3.5 ± 1.7 (37)	4.3 ± 1.8 (23)	2.6 ± 1.4	3.9 ± 2.2	0.7 ± 0.6	1.0 ± 0.8
yelps	16	35	3	4	2.4 ± 1.3 (10)	2.6 ± 1.4 (7)	3.0 ± 1.3	4.1 ± 2.5	0.4 ± 0.4	0.4 ± 0.4
chirp trains	22	70	3	12	6.2 ± 3.3 (10)	4.3 ± 2.4 (46)	7.5 ± 3.9	6.3 ± 2.5	0.9 ± 0.5	1.1 ± 0.6
up trills	12	3	5	2	1.5 ± 0.3 (19)	1.4 ± 0.2 (6)	5.4 ± 0.8	4.3 ± 0.8	1.1 ± 0.1	1.6 ± 0.6
Pulsed Sounds										
buzz	10	31	4	5	4.8 ± 1.9 (7)	5.5 ± 0.7 (16)	6.1 ± 2.4	7.7 ± 0.9	0.8 ± 0.2	1.1 ± 0.4
tonal scream	0	23	0	6	-	1.7 ± 0.2 (18)	-	2.4 ± 0.5	-	0.9 ± 0.2
broadband scream	0	12	0	3	-	4.2 ± 1.5 (6)	-	6.0 ± 1.9	-	1.4 ± 0.5

[1] Percent occurrence of call types was evaluated from those spectrographic segments (30 s) in which beluga vocalizations were present.
[2] Student's t-test was applied where sample sizes were adequate. * P<0.01.

P<0.01). Chirp trains that were heard primarily in noisy periods achieved the highest final frequencies ($\bar{x}$ = 7.5 kHz) of any tonal signal and the two pulsed sounds, the buzz and the broadband scream, achieved the highest frequencies ($\bar{x}$ of 7.7 and 6.0 kHz) of all signals. Although these higher-frequency signals were used in disturbance situations, there was no evidence of a general upward shift in the frequencies of tonal signals; there were no significant differences in the average initial/lowest frequency (3.8 ± 2.5 vs. 3.6 ± 2.1 kHz, respectively) or average final/highest frequency (4.2 ± 2.9 vs. 4.3 ± 2.7 kHz, respectively) of all tonal signals in quiet vs. disturbance periods.

Generally, belugas increased the duration of many of their signals in situations of ship disturbance. The average duration of tonal signals during disturbance periods was significantly longer than that during quiet periods (0.9 ± 0.6 vs. 0.7 ± 0.5 s, P<0.01). Chirp trains, heard primarily during disturbance periods, were the longest duration ($\bar{x}$ = 1.6 s) of any social signals. One conspicuous call associated with a disturbance reaction was the falling tonal which was significantly (P<0.01) longer in average duration than during quiet periods. The durations of 'morse' tonals also increased significantly during disturbance periods.

These measurable characteristics of wider frequency excursions and longer durations, along with distinctive call types, gave a distinctive aural impression of 'alarm' or 'excitedness' by belugas in situations of disturbance.

Ice Crack Formation and Whale Responses (2-3 July)

Ice Crack Formation

On 2 July both ships undertook several maneuvers in attempting to cross over the shear zone into Admiralty Inlet (see Fig. 2). The MacDonald finally accomplished the crossover around 17:00 but was forced to return to assist the Arctic, which was unable to maneuver around a sharp corner in the MacDonald's track. This series of movements apparently caused destabilization of the solid ice in the vicinity and in Lancaster Sound. At 16:00, a huge sheet of ice on the north side of the ship track broke loose and began rafting slowly against the ship track. Much of the track (~40 km) became tightly closed and at the acoustic camp the northern ice sheet advanced over the shore fast ice sheet causing us to abandon the site. Through this displacement a major ice crack was formed from the centre of the Lancaster Sound ice edge to near the apex of the ship track near Admiralty Inlet (see Fig. 31).

Whale Behaviour

Prior to the formation of ice cracks in the late afternoon of 2 July, there was relatively little whale activity in the area of the bight. Small numbers of narwhals (max. 9) were observed during scan samples between 06:00 and 09:30 and most (65%) were involved in circling movements. None were noted during the remainder of the day.

Small numbers (max. 10) of belugas were present throughout most of the day except for a short period between 09:15 and 11:15 when they appeared to move away from the bight. After 17:00 there was a marked movement of belugas from the east into the bight and at 18:00, as the fast ice began to move, about 50 belugas were actively diving beneath the rafting ice sheets at the former position of the ship track. Their diving activity was unusual and appeared 'excited'--exhalations were loud (sometimes accompanied by flatulent sounds) and movements appeared rapid with animals rising unusually high out of the water. Most of the belugas appeared to be adult males organized into distinctive pods, several of which were observed moving rapidly beneath the ice along the former ship track. Although some animals reappeared from beneath the ice edge it was apparent that many were finding open water somewhere farther to the west as their exhalations could be heard from that direction.

After 19:00 the belugas disappeared from the ice edge, apparently finding open water westward along the former ship track. Later, while we were moving camp by snowmobile along the ship track, several belugas and a few narwhals were seen in isolated areas of open water in the ship track. The camp was temporarily re-established around midnight along the ship track about 6 km west of the former camp (#4). The northern ice sheet appeared to have ceased moving at this time and we awaited the helicopter in order to reconnoiter the situation. Two parties of hunters had arrived during the day and during the night they took a male narwhal and an adult beluga in the ship track.

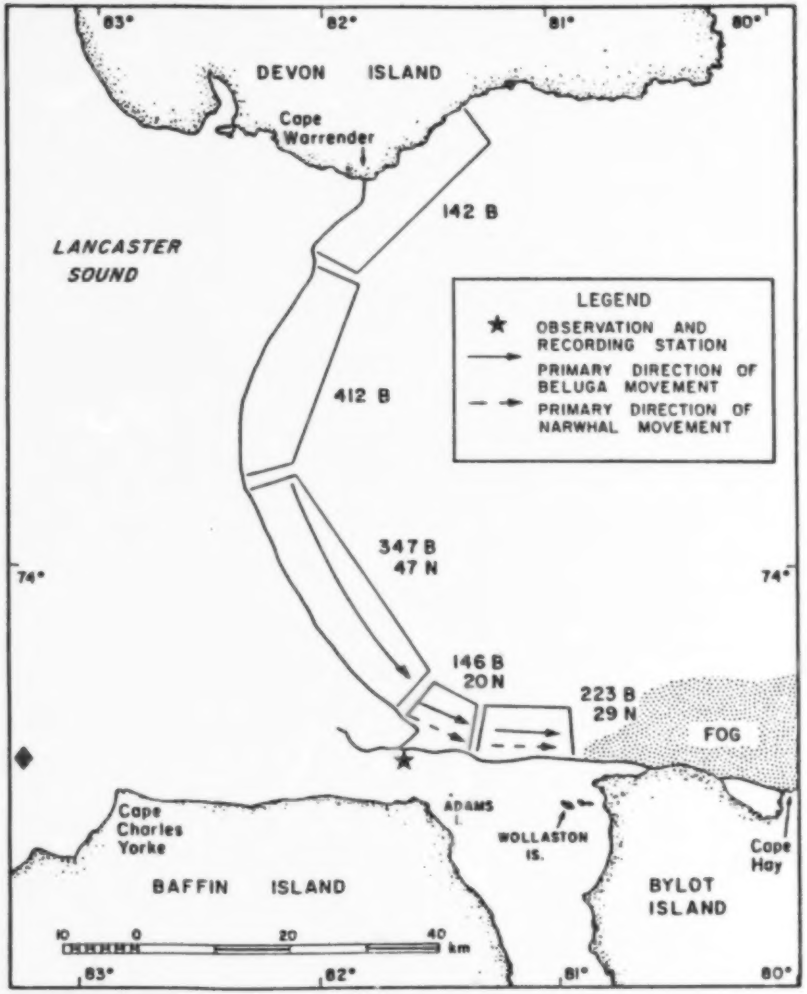
Vocal Behaviour

A recording obtained at 18:03, just before the northern ice sheet encroached over the recording site, was dominated by a remarkable variety of beluga vocalizations punctuating with impulsive broad-band cracking sounds from the moving ice. The entire repertoire of beluga call types was represented in a 30 s segment of spectrograph. Most notable was the use of harsh buzzes (10 in 30 s) that had seldom been heard outside the context of ship disturbance. Long trains of chirp series along with many single chips were heard continuously throughout the segment. These were overlain with many long (max. 1.3 s), irregular undulating and accented tonals. The combination of sounds along with the long durations and wide frequency excursions of the calls gave the aural impression of excitement. No narwhals were seen in the area at this time and none of their sounds were heard.

Distribution and Numbers

An aerial survey was conducted on 2 July between 11:07 and 12:28, prior to the formation of the major ice crack to the west. Dense fog prevented coverage of the Bylot Island coast where large concentrations of whales had been observed during recent surveys. Occasional thin patchy fog to the north along the Lancaster ice edge limited visibility at times. A total of 1270 belugas were distributed all along the portion of the ice edge that could be surveyed (Fig. 31A).

Narwhals were recorded in small numbers (total of 96) along the three southernmost ice edge segments. Belugas in the bight and adjacent ice edge segment were moving southeast along the ice edge. Narwhals in the bight and the ice edge segment southeast of the bight were also moving in a southeasterly direction.


83°
82°
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DEVON ISLAND
Cape Warrender
LANCASTER SOUND
142 B
412 B
347 B
47 N
146 B
20 N
223 B
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74°
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Cape Charles Yorke
ADAMS I.
WOLLASTON IS.
Cape Hay
BAFFIN ISLAND
BYLOT ISLAND
10
0
20
40
km
83°
82°
81°
80°

Fig. 31A. Distribution and numbers of narwhals and belugas recorded during survey 14, 11:17-12:28, 2 July 1983. Totals of 96 narwhals and 1270 belugas were recorded. Fog prevented a survey of the eastern portion of the Navy Board Inlet ice edge and the coast of Bylot Island. The positions of the MV Arctic and CCGS John A. MacDonald at the time of the survey are indicated by a diamond.

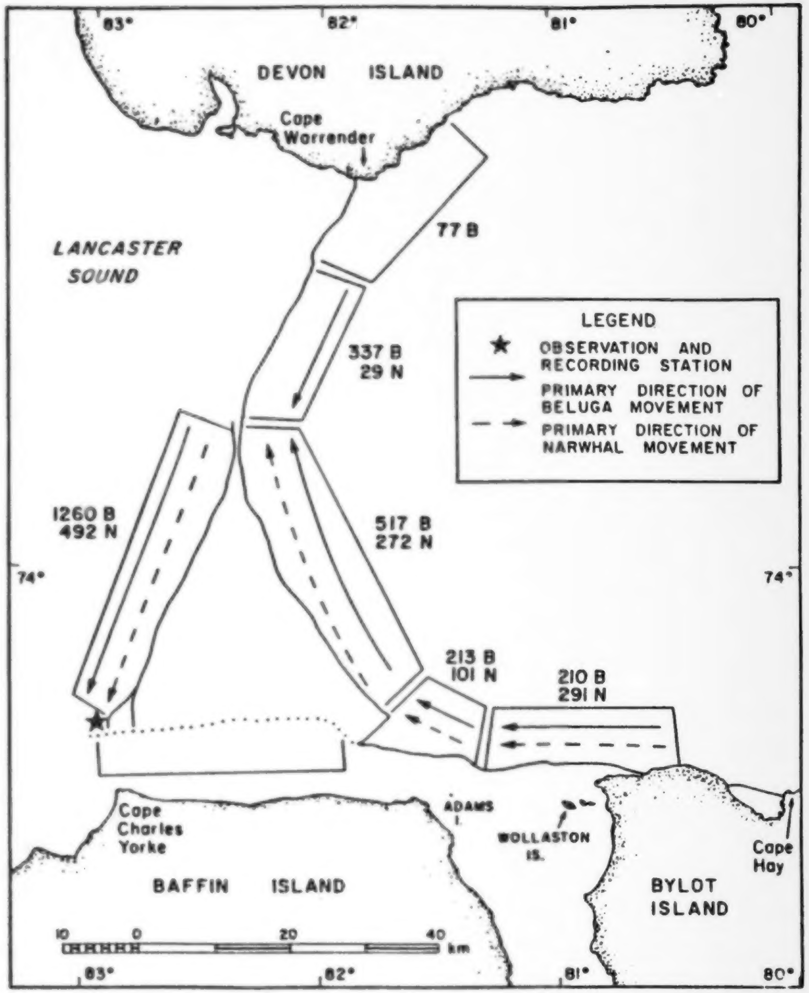

83°
82°
81°
80°
DEVON ISLAND
Cape Warrender
LANCASTER SOUND
77 B
337 B
29 N
1260 B
492 N
517 B
272 N
213 B
101 N
210 B
291 N
LEGEND
★ OBSERVATION AND RECORDING STATION
PRIMARY DIRECTION OF BELUGA MOVEMENT
PRIMARY DIRECTION OF NARWHAL MOVEMENT
74°
74°
Cape Charles Yorke
ADAMS I.
WOLLASTON IS.
Cape Hay
BAFFIN ISLAND
BYLOT ISLAND
10
0
20
40
km
83°
82°
81°
80°

Fig. 31B. Distribution and numbers of narwhals and belugas recorded during survey 15, 10:55-12:45, 3 July 1983. Totals of 1185 narwhals and 2614 belugas were recorded.

At 10:55 on 3 July an aerial survey was begun under ideal conditions along the entire Lancaster Sound ice edge, the ship track and the large recently-formed ice crack that ran from the centre of the ice edge to near the apex of the ship track (Fig. 31B). A total of 3799 whales--1185 narwhals and 2614 belugas--were recorded. A large percentage of the narwhals (42%) and belugas (48%) recorded during this survey occupied the ice crack. The crack was as wide as 50 m near the ice edge but became narrower toward the apex where it varied from 5 m wide to being closed. Large numbers of whales were found along its entire length and virtually all of them were moving southwest through the crack toward the ships. Because of the remarkable density of both species the counts of 492 narwhals and 1260 belugas are certainly minimal figures. The density of 38.9 whales/km was impressive.

Whales recorded along the ice edge were moving strongly toward the area where the ice crack closely approached the ice edge. Thus, this area along the middle of the Lancaster Sound ice edge appeared to be the main point of access to the ice crack. Most of the length of the ship track was tightly closed and no whales were observed along its length. The number of narwhals (1185) recorded during this survey was more than twice the previous high count of 455 on 1 July, while the number of belugas (2614) recorded was comparable to the 2293 seen on 1 July. The large number of narwhals represents a major influx of narwhals into the study area, presumably from offshore areas. This influx coincided with the appearance for the first time during the study of many females and immatures.

At 12:34, the vanguard of the whales moving through the crack were just arriving at its apex where it joined the ship track. At the south end of the ice crack, the narwhals and belugas were within about 23 km of the ships. Both ships were operating during this period but underwater recordings at the ice crack were not obtained until 15:15 at which time only the MacDonald was operating. Received noise levels (with considerable input from narwhals) were 103 dB//1 μPa in 20-1000 Hz band at 20 m depth during a strong forward phase. Two encampments of hunters were present along the ship track near this location; one narwhal had been taken.

Hunter Activity

At 14:00 an observer was placed along the ice crack about 1.5 km from the ship track. Large numbers of belugas and narwhals were moving rapidly along the crack toward the ship track at this time. However, at 14:10 the movement suddenly appeared to reverse and animals were moving in both directions. Possibly they had reached the end of the ice crack around this time; or they may have been reacting to the landing of the helicopter or to hunters who killed a male narwhal in the ship track about this time. Between 14:15 and 14:30, 68 narwhals and 4 belugas passed by, moving north in the ice crack toward the ice edge. Although most of the animals at the vanguard of this movement were adult males, 25% of the narwhals were females and immatures.

After 15:00 the whale activity near the terminus of the ice crack ceased as hunters pursued the whales. At least eight shots were heard between 15:30 and 17:00. This marked the beginning of a major narwhal hunt that continued throughout the remainder of the study. Small groups of male narwhals appeared intermittently in the ice crack later in the afternoon on 3 July but their behaviour was obviously influenced by the hunting activity. One adult male was observed bleeding profusely from a wound.

Hunting Activity and Whale Distribution

4 July

In the morning of 4 July, the wounded narwhal from 3 July was found dead, floating in the ice crack near camp #5. It was an adult male 473 cm in length with a broken tusk (142 cm plus an estimated 40 cm missing piece). Hunting activity continued intermittently but was apparently reduced due to fog. Another adult male narwhal was found dead in the ice crack late in the day. It measured 464 cm and, surprisingly, had no erupted tusk, an unusual occurrence. Both animals had been mortally wounded but apparently lost by the hunters.

Small numbers of narwhals and belugas appeared intermittently throughout the day and high frequency recordings were taken on an opportunistic basis.

5 July

Poor weather conditions precluded an aerial survey on 5 July. Hunting activity continued intermittently and few whales appeared until later in the day when hunting activity ceased for a while. At about 20:30 there was a notable southward movement of adult male narwhals along the ice crack. Between 20:35 and 22:00, 98 narwhals passed by; all except four were males. Twenty-two belugas, both adults and immatures, passed by during the same period. About 21:55 a shot was heard and at 22:04 the first of several groups of narwhals passed by moving northeast back along the crack. The diving activity became confusing with animals diving in both directions and recognizable groups reappearing several times.

6 July

Hunting continued in the early morning of 6 July; eight more hunters arrived from Arctic Bay in the morning. The fog that persisted throughout the morning began clearing in the late afternoon and we were able to conduct an aerial survey of the ice crack, ice edge and ship track beginning at 16:30 (Fig. 32A). During this survey we counted six narwhals that had been taken by the hunters. The overall whale distribution was very similar to that observed during the previous (3 July) survey, with the exception that narwhals and belugas were now also occupying the ship track. In total, 720 narwhals and 2348 belugas were recorded. The total number of whales seen (3068) was about 700 fewer than during the 3 July survey. Narwhals accounted for most of this decrease.

7 July

Hunting activity continued throughout 7 July and whales remained away from the hunting camps located on the ice cracks near the ship track. A complete aerial survey of the ice crack, the ship track and the ice edge was conducted between 10:13 and 12:04 under ideal conditions. Only 28 narwhals and 698 belugas were seen in the ice crack and small numbers of narwhals (74) and belugas (62) were found in the ship track (Fig. 32B). Substantial numbers of belugas (1054) were found along the Lancaster and Navy Board ice edges, but only 129 narwhals were recorded along these features. The total number of narwhals recorded during this survey was down by about 1000 whales

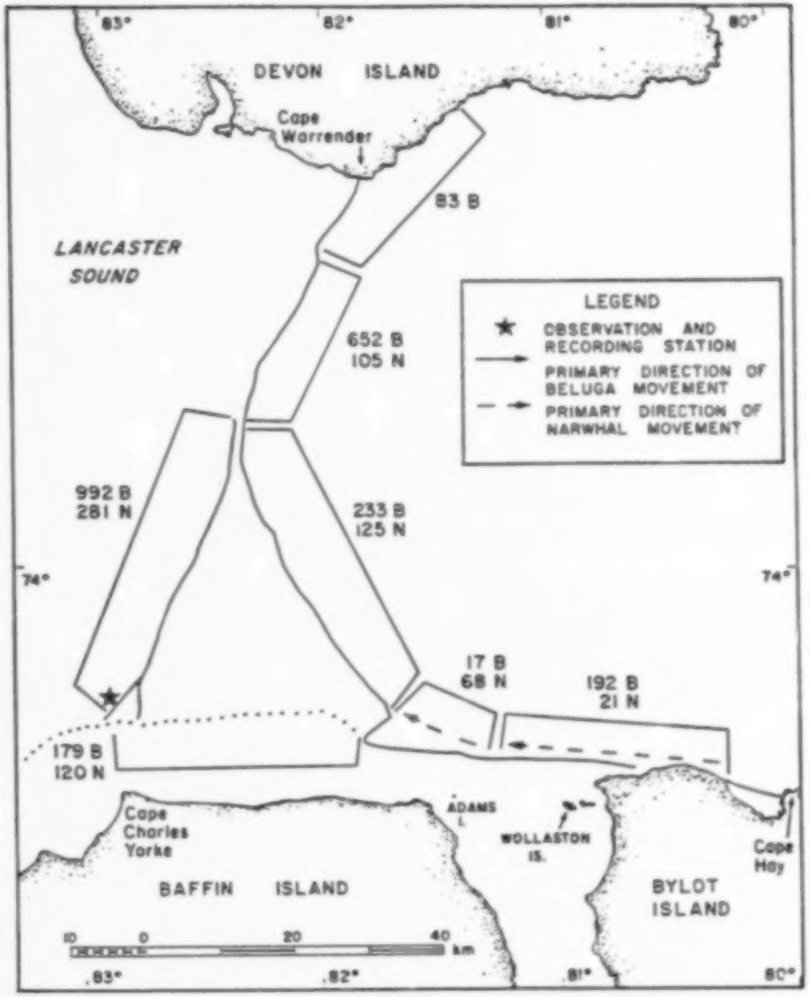
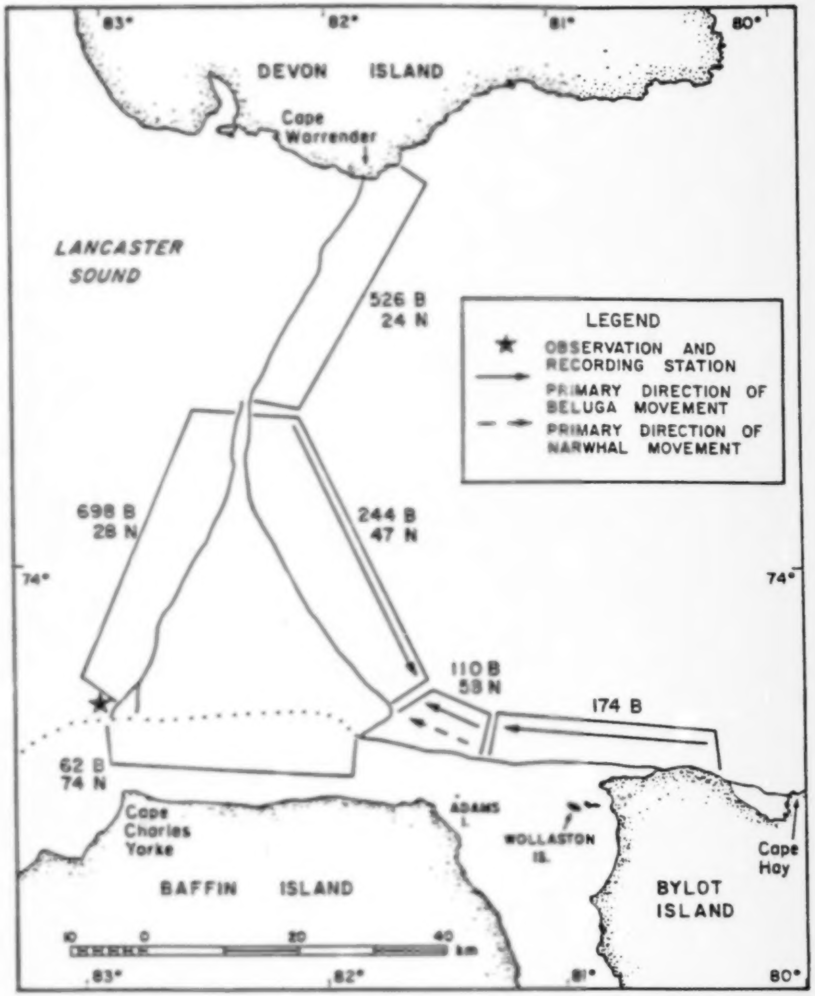

83°
82°
81°
80°
DEVON ISLAND
Cape Warrender
LANCASTER SOUND
83 B
652 B
105 N
992 B
281 N
233 B
125 N
17 B
68 N
192 B
21 N
179 B
120 N
74°
74°
LEGEND
★ OBSERVATION AND RECORDING STATION
PRIMARY DIRECTION OF BELUGA MOVEMENT
PRIMARY DIRECTION OF NARWHAL MOVEMENT
Cape Charles Yorke
ADAMS I.
WOLLASTON IS.
Cape Hay
BAFFIN ISLAND
BYLOT ISLAND
10
0
20
40
km
83°
82°
81°
80°

Fig. 32A. Distribution and numbers of narwhals and belugas recorded during survey 16, 16:28-18:25, 6 July 1983. Totals of 720 narwhals and 2348 belugas were recorded.


83°
82°
81°
80°
DEVON ISLAND
Cape Warrender
LANCASTER SOUND
526 B
24 N
698 B
28 N
244 B
47 N
110 B
58 N
174 B
62 B
74 N
74°
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LEGEND
★ OBSERVATION AND RECORDING STATION
PRIMARY DIRECTION OF BELUGA MOVEMENT
PRIMARY DIRECTION OF NARWHAL MOVEMENT
Cape Charles Yorke
ADAMS I.
WOLLASTON IS.
Cape Hay
BAFFIN ISLAND
BYLOT ISLAND
10
0
20
40
km
83°
82°
81°
80°

Fig. 32B. Distribution and numbers of narwhals and belugas recorded during survey 17, 10:13-12:04, 7 July 1983. Totals of 231 narwhals and 1814 belugas were recorded.

from the 3 July survey and by about 500 from the previous (6 July) survey. Five hunting camps were located at the bifurcated southern end of the ice crack and about 15 hunters were seen during the survey. Sixteen narwhal carcasses and an additional dead whale that had apparently been lost by the hunters were recorded.

8 July

At noon on 8 July, the fast ice began to shift and an ice crack formed close to camp. The hunters quickly prepared to move toward more solid ice in Admiralty Inlet. We conducted a brief recording at 13:15 and were surprised to hear strong narwhal clicking since no narwhals had been seen in the area during the last two days. The helicopter arrived at 15:45 and as we were packing up camp we saw several groups of male narwhals moving toward Admiralty Inlet along newly formed cracks. A survey was cut short by the presence of heavy fog about 15 km to the north of the recording camp. Along the portion of the ice crack that was free of fog we encountered 74 belugas and 95 narwhals. Along a short portion of the ship track (between the two southern ends of the ice crack) and a newly formed crack that radiated out from Cape Charles Yorke to the ship track we recorded another 72 narwhals. The ship track south of the shear zone was still jammed with rubble ice and it appeared impenetrable to the whales. Five hunting camps and 23 narwhal carcasses were encountered.

10 July

Our final aerial survey was conducted on 10 July under poor weather conditions, with high sea states (Beaufort 4) along the ice edge. Only 177 belugas and 31 narwhals were recorded in the ice crack. Numbers recorded were also low along the ice edge (468 belugas and 217 narwhals), with most of these occurring along the Navy Board Inlet ice edge. One beluga and nine narwhals were recorded in the ship track and 56 belugas were observed in the shore lead west of Cape Warrender, along the Devon Island coast. Totals of only 646 belugas and 257 narwhals were recorded during the survey. On our return flight we refueled at Cape Charles Yorke. The outflow from the Charles Yorke River had created a small polynia in which about 500 belugas were swimming and rolling in the shallows.

DISCUSSION

Influence of Ice Conditions on Whale Distribution in Lancaster Sound

The spring location of the Lancaster Sound ice edge is highly variable from year to year and greatly influences the distribution and timing of migrations of narwhals and belugas through the channel. In light ice years the ice edge may occur far to the west in Barrow Strait. In 'heavier' ice years such as 1983 it may be located close to the entrance of the passage. In the last decade the positions of the ice edge have more often been near the entrance of the sound than was the case in earlier years (LGL Ltd. 1983). It is within the context of this linear feature that the normal patterns of distribution, abundance and behaviour of narwhals and belugas were evaluated in the pre-disturbance period.

Belugas

In years when Lancaster Sound is not covered by fast ice, the peak of beluga migration occurs in late June and early July and the whales follow the south coast of Devon Island toward their summering grounds in the central archipelago (Davis and Finley 1979). In 'heavy' ice years the fast ice forms a barrier to westward migration, resulting in dense concentrations of belugas along the ice edge (Koski and Davis 1979; Koski 1980). Such was the case in 1983. The position of the 1983 ice edge, east of Admiralty Inlet, was very similar to the positions in 1978 and 1979, and patterns of distribution, numbers and behaviour among these years were comparable. The maximum number of belugas observed during the pre-disturbance period of this study (939 belugas; 7.2/linear km of ice edge) falls within the general range of numbers (850-1640) found along the ice edge in mid-late June of 1978 and 1979.

The movements and behaviour of belugas are strongly influenced by the Lancaster Sound ice edge. Previous surveys have shown that belugas associate strongly with the ice edge or adjacent coastal waters; almost none are found in offshore waters away from the ice edge (Koski and Davis 1979; Koski 1980). The 1983 surveys showed that the majority of the whales occurred within 400 m of the ice edge and that their movements were generally parallel to this feature. Movements were often largely unidirectional over long segments of the ice edge. Rates of casual, directed swimming indicate an average speed of about 6.4 km/h. Occasionally belugas engaged in circling movements and dives that were invariably directed beneath the ice edge. However, there was no evidence of intensive feeding activity along the ice edge during the pre-disturbance period of this study. Thus, it appears that the main "activity" of belugas along the Lancaster Sound ice edge is waiting for break up, and their movements tend to be casual and perhaps exploratory.

As in previous years, the age composition of the segment of the beluga population that occupies the Lancaster Sound ice edge in mid June includes a preponderance of adults (76% in 1978, 78% in 1983) among these first arrivals. More detailed information from the 1983 studies indicates that most (61%) of the adult population along the Lancaster Sound ice edge are probably males (i.e. either in distinctive pods or adults not accompanied by immatures).

Narwhals

Unlike belugas that follow coastal routes or ice edges during spring migration into Lancaster Sound, narwhals are much more pelagic in habit, arriving in the spring (May-June) in a broad-front migration through the pack ice of northern Baffin Bay. Although some of the population move west through Lancaster Sound as ice conditions permit, the major summering grounds of the narwhal occur in the fiord complexes of northern Baffin Island, particularly Eclipse Sound and Admiralty Inlet. Thus, the existence of an ice edge across Lancaster Sound does not constitute such a major barrier to migration as it does with belugas. Extensive aerial surveys of northern Baffin Bay in the 'ice barrier' years of 1978 and 1979 showed that, although minor concentrations (few hundred) of narwhals do occur along certain ice edges, most of the population remains in the offshore pack ice until July when the fast ice deteriorates sufficiently to permit the animals access to their traditional summering areas. Maximum numbers of 119 narwhals (0.9/linear km) observed along the Lancaster Sound ice edge during the pre-disturbance period of 1983 are similar to densities observed in previous years (e.g., max. of 85 in mid June 1978 and 175 in 1979). The fact that narwhals were found almost exclusively along the southern third of the ice edge is generally consistent with observed distribution patterns in previous 'ice-barrier' years and presumably reflects the narwhals' attraction to its summering areas in northern Baffin Island. The main influx of narwhals into the summering areas does not occur until around mid July when the fast ice deteriorates sufficiently to allow access (Finley and Gibb 1982) and it is reasonable to assume that, during this study, large numbers of narwhals remained in offshore areas among the pack ice (see Koski and Davis 1979; Koski 1980).

Like belugas, those narwhals that are in the general area of the ice edge maintain a close association with the ice edge; the majority (64%) were found within 400 m of the edge. Again as with belugas, the movements of narwhals along the ice edge were mostly parallel to it but their movements generally appeared less-strongly directed--19% of the narwhals seen during the pre-disturbance period of this study were reported to be engaged in circling/diving movements or were resting. Virtually all deep diving activity of the narwhal was directed beneath the ice edge but there was no evidence of intensive feeding activity. These observations support the contention of Finley and Gibb (1982) that the attraction of narwhals to ice edges is not related to special feeding opportunities; rather they are awaiting the development of leads and ice cracks in order to proceed to their summering areas. This movement is often undertaken in the most restrictive of ice conditions and adult males precede females and immatures (Finley and Miller 1982). The fact that over 90% of the narwhals observed along the Lancaster Sound ice edge in 1983 were adult males is consistent with this behaviour pattern.

Observed Responses of Whales to Ship Disturbance

Observations of the response of narwhals and especially belugas to the open-water approach of the ore-carrier MV Arctic in 1982 and again in 1983 provide complementary and corroborative evidence of the high degree of sensitivity of these whales to ship noise. The 1983 data further enhance our understanding of the markedly different behavioural responses shown by the two species. The results of the 1983 study suggest that the sensitivity of the whales to ship noise is even greater than was indicated by the 1982 study. In 1983, visible changes in the surface behaviour and audible changes in underwater vocal activity indicated that whales were aware of the ship's approach when it was in excess of 80 km from the ice edge. A strong avoidance reaction by belugas was observed in 1982 when the ship was 35-40 km away and in 1983 when it was 43-49 km away. In contrast to the beluga's 'flee' response, narwhals exhibited a 'freeze' behaviour during the same periods in both years. Both species vacated the disturbance area well in advance of the ship's arrival. In both years, narwhals were the last to leave the area. Belugas consistently demonstrated a greater degree of sensitivity to disturbance than did narwhals.

Two distinctive behavioural responses to the open-water approach of *Arctic* were identified in the 1982 study and further verified in the 1983 study--the flee response of the beluga and the 'freeze' response of the narwhal. In a comparative format, the observable or audible behavioural traits that constitute the two patterns are as follows:

Belugas	Narwhals
- rapid movement	- slow movement or motionless
- herd cohesion but loss of pod integrity	- pod cohesion, body contact no herd formation
- diving asynchronous, shallow, 'porpoising'	- sinking submergence
- strongly pagophilic (i.e. ice 'hugging') and coast-seeking, sub-ice movement	- strongly pagophilic, possibly offshore seeking, sub-ice movement
- alarm calls	- silent

These distinctive behavioural patterns are thought by the Inuit to be typical 'fright' reactions of these two species. The responses are designated 'ardlingayuk' in Inuktitut--meaning 'fear of killer whales'. The designation is perhaps appropriate since the primary fear-avoidance response of these two species has probably developed in response to long exposure to predation by killer whales (*Orcinus orca*), probably the only significant natural predator of belugas and narwhals. (Human 'predation' through advanced technological means is a recent phenomenon and there is little evidence that these whales have developed appropriate survival strategies in response.) Belugas are known to react strongly to projected sounds of killer whales, and this response has been used to deter belugas from using traditional areas (Fish and Vania 1971). The initial responses of belugas and narwhals to an approaching ship are consistent with Inuit observations of 'ardlingayuk' behaviour--both species seek shelter in the ice and belugas move into shallower waters.

Auditory Sensitivity

The long-range responses shown by both species to the open-water approach of the Arctic is unprecedented. This may be largely explained by the fact that no similar field studies have been conducted in pristine marine environments with industrially-naive populations of marine mammals. In this regard, high arctic populations of whales are particularly naive since they are exposed to very low levels of shipping activity; their responses may be exaggerated relative to populations that are exposed to more frequent ship traffic. For example, in studies in the industrial area of the Mackenzie Delta the maximum reported range of a vessel (a tugboat) that evoked a notable avoidance response by belugas was 2.4 km (Fraker 1977). However, this example is undoubtedly not comparable since noise attenuation would be very rapid in the extremely shallow waters and soft muddy bottom of the Mackenzie Delta. The relatively deep waters of Lancaster Sound would be expected to have much better sound transmission properties.

Ford (1977) suggested that the mere presence of a foreign sound such as a ship may not be sufficient to cause a reaction by belugas, but that sound level was probably important. He further suggested that moving sound sources had a greater effect than stationary ones. It is generally agreed that marine mammals, including belugas, are more likely to show avoidance reactions to vessels if there are sudden changes in course, speed and noise levels (see review by Richardson et al. 1983). Our observations of the strong reactions of belugas and narwhals to the rapid open-water approach of ships are in agreement with these views. The sudden start-ups and highly variable noise levels associated with ramming and backing of the ice breakers may have evoked stronger reactions in the belugas than if the noise source had been constant. The fact that belugas and narwhals returned to the disturbance area when noise levels were higher than those to which they initially reacted suggests that their initial responses were startle responses, and that their sensitivity to ship noise declined subsequently.

Displacement

In 1982, the arrival of Arctic caused the belugas to vacate the Admiralty Inlet ice edge and to occupy adjacent coastal areas. We were unable to ascertain the maximum displacement of whales resulting from the initial arrival of Arctic in 1983. However, aerial surveys during the second disturbance period (start-up of Arctic, arrival of MacDonald) showed (1) a marked hiatus (94 km) in the distribution of belugas along the ice edge, and (2) notable concentrations near either end of the ice edge and along the adjacent coast. It is interesting that the hiatus in distribution occurred unevenly on either side of the ship track. The aerial surveys showed that those belugas that had departed to the south in response to Arctic's start up had stopped moving after travelling about 18 km along the ice edge to the coast of Bylot Island. In contrast, animals that departed north along the ice edge continued moving north until many reached the coast of Devon Island about 85 km away. Observers placed briefly on the coastal cliffs of Bylot Island, shortly after the arrival of MacDonald, noted that a large movement of belugas east along the coast suddenly stopped and returned to the ice edge while the ship was still operating about 22 km away. These anecdotes suggest that the beluga is both pagophilic and shallow-water seeking in response to a perceived threat. The greater displacement of belugas on the offshore side of the ship disturbance may be indicative of their sense of vulnerability in offshore areas. Although survey coverage was sometimes incomplete after the second disturbance, it appeared that belugas did not fully re-occupy the southern half of the ice edge, particularly around the disturbance area, until early July during the seventh disturbance period.

Narwhals showed little displacement compared to belugas. The maximum distributional hiatus was 37 km north and 18 km south of the ship track during the second disturbance period. While belugas continued to move strongly toward the coast, narwhal movement ceased and some of them evidently dispersed offshore. These observations are in general agreement with the experience of KJF and GWM who have often observed the fright response of these two species in a variety of situations (e.g., Finley and Miller 1982; Finley et al. 1982). Beyond the second disturbance period there was no evidence that ship activity resulted in displacement of narwhals; in fact they appeared to concentrate in the vicinity of the ship track, possibly in anticipation of an access route toward their summering grounds.

Signal Context and Vocal Responses of Whales to Ship Disturbance

Vocal signals are probably the primary form of communication in odontocete whales, and, in common with most vertebrates, it is reasonable to assume that vocal signals convey information about the arousal and motivational state of the signaller. This being said, it is quite another matter in acoustic studies of whales to be able to correlate the vocal signal to a specific behavioural or environmental context, especially when dealing with a remarkably complex and integrading vocal repertoire such as that of the beluga.

Belugas

Undoubtedly, the most notable change in the belugas repertoire in response to ship noise was the shift to pulsive calls, particularly the broadband and tonal screams that were first identified in the 1982 study. These calls were heard in virtually all disturbance situations (either ship approach or sudden start-up) in the 1983 study. Their coincidence in both years with the panic movement of belugas in response to the ship suggests that these calls represent a first-order alarm signal. These calls were not heard in any other situation supporting the contention that when a premium exists for unambiguous vocal signals in the absence of other signal modalities, calls will tend to be discrete (Marler 1965). The fact that these calls were clearly audible at the 'satellite' station in 1983 indicates a strong source level; this feature along with the wideband frequency distribution and relatively long duration constitute appropriate attributes of a generalized alarm signal (Zahavi 1982; Gouzoules et al. 1984). The advantage of such a long range signal may be evident in the overall coordination of herd movements over long distances.

The other pulsed sound, the buzz, heard primarily in the context of ship disturbance, may indicate a heightened level of excitement since it was heard (less frequently) in other behavioural contexts. For example, several buzz sounds were heard from a highly active group of belugas that were apparently anticipating the formation of ice cracks or break-up of the Lancaster Sound fast ice on 2 July 1983.

Tonal vocalizations are the most commonly used social signal by odontocete whales and they probably find their greatest expression in belugas ('sea canaries'). Tonal signals tend to be species-specific (Steiner 1981) and in some species tonal signals have been shown to function as 'signature' calls, i.e. to identify individuals and assist in locating them (Caldwell and Caldwell 1965). The emotional state of individuals has been thought to be transmitted through variations of rapidity, repetition rate, loudness and/or duration of the basic signal contours. For example, the Caldwells stated that dolphins (Tursiops truncatus) recorded in a variety of stressful situations produced no whistles other than 'excited' variants of signature whistles. They concluded that there was no evidence of a special distress signal. However, Dreher and Evans (1964), who studied the whistle calls of four species of dolphins, found that one general whistle type common to all was the downswept tonal, a signal that was 'definitely associated with great fright and disturbance'. It is this whistle type that we heard so often, along with the pulsed scream, in the context of disturbance (particularly in the initial phases such as approach and start-up of the ships) and panicked movement of belugas. This call was particularly noticeable during the approach of the MV Arctic in 1983 and was clearly audible at the 'satellite' station, thus indicating a strong source level.

One other tonal signal, chirp trains, was heard primarily in the context of ship disturbance, but unlike the pulsed screams and downswept tonals, these calls persisted beyond the initial alarm calls, giving the impression of sustained excitedness. These calls were conspicuous by their high frequency emphasis but in their regularity of repetition and duration, they were structurally similar to the lengthened 'morse' tonals that were also heard in situations of disturbance. These signals along with the wider frequency excursions and longer durations of other tonal calls gave the aural impression of excitedness in situations of disturbance. The spectrum of tonal signals used in the context of disturbance was also distinctive by the absence of certain signals (e.g. upward-inflected, uptrill and stepped tonals) heard during quiet periods.

Narwhals

Although the narwhals' vocal repertoire is much more monotonous-sounding than the beluga, it is likely that its signals carry the same level of informational content. Ford and Fisher (1978) suggested that individual identity was encoded within the variable-frequency structure of its pulsed calls. Watkins et al. (1971), noting the similarity between the low-frequency click series of the narwhal and the sperm whale (*Physeter catodon*), suggested that the clicks contained informational content such as individual identity and position. Ford and Fisher (1978) suggested that click series were used primarily in echolocation tasks and they suggested that the low-repetition rate series could function in range-finding and topographical analysis.

In support of and/or in contradiction to the above hypotheses we provide the following observations:

1. Low-frequency click series are the prevalent sound produced by narwhals in Lancaster Sound and are frequently heard in the absence of other narwhal sounds. This suggests that individuals maintain acoustic contact by click signals.
2. The most notable aural impression from listening to recordings of narwhals in their summering areas is that pulsed calls are much more prevalent than in spring at the ice edge. At this time of year, narwhals appear to engage in more social activity involving mixed herds (Silverman 1979; Finley and Gibb 1982). Pulsed calls undoubtedly function as an important social signal in this context, whereas at the ice edge the primary behaviour appears to be exploratory and it might be expected that orientation clicks would be used more often.
3. Narwhals arriving in newly-formed ice habitat utilized click series signals almost exclusively (see p. 72). Prior to undertaking exploratory dives, narwhals were observed making sweeping motions with the anterior portion of their bodies while apparently emitting click series (see p. 68). In both cases, click series may have served an exploratory ('echo-scanning') function.

4. Three properties of low-frequency click series--regularity of repetition rate (i.e. no evidence of ranging), apparent omnidirectionality (i.e. not beamed or focused), and signal locatability--might be appropriate attributes of a communication signal. In these respects the low-frequency click series of narwhals bear a resemblance to the click series of sperm whales. Like the sperm whale, the narwhal is pelagic in habit and appears to be a deep-diving teuthophage; such behavioural and habit similarities might favour the development of parallel sensory modalities for maintenance of spatial organization.

5. Ford and Fisher (1978) suggested that the slower click series of narwhals would be appropriate for the depth range (20-150 m) of waters in which they recorded. By extension, it might be expected that the click repetition rate would decrease over deeper waters and indeed, the average click repetition rate of 5.5/s that we found (in areas where depth varied between 575-725 m) appears to be lower than the distribution of repetition rates illustrated (no mean given but roughly 8/s) by Ford and Fisher. However, we are suspicious of this simplistic correlation--it seems unlikely that narwhals would utilize near-continuous bottom-scanning in an area where relatively little feeding takes place and where ice probably constitutes the primary navigational stimulus.

In summary, it appears that the pulsed call of the narwhal conveys emotional information and, possibly, identity. Low-frequency click series may be used in echo-ranging and/or in communication (e.g., position and identity).

The only audible response of narwhals that we could discern in situations of ship disturbance in 1983 was a cessation of sound, but this occurred only in the initial phases of disturbance when the ship was approaching the ice edge. This response was noted in the 1982 study and confirmatory evidence was obtained on an opportunistic basis in the summer of 1984 when K. Finley recorded the underwater response of a large group of narwhals that were being chased by hunters in outboard-powered boats. The silent behaviour corresponds with their observable surface activity--the 'freeze' behaviour--in situations of distress. In our considerable experience with the behaviour of narwhals in stressful situations (e.g., Finley et al. 1980; Finley and Miller 1982), we have never observed a rapid, mass-movement of the narwhal that might require the use of a herd-coordinating alarm signal like that of the beluga. These observations fit within an 'ardlingayuk' behavioural model if the narwhals primary survival strategy is to remain undetected (visibly and audibly) by its underwater predators. Except during the initial phases of disturbance when narwhals remained silent as the ship approached, subsequent ship start-ups provoked, at most, a 5 s silence. A shot fired into the water by hunters about 2 km from our recording camp had the same transient effect on dense click 'clatter'. There was no evidence that ship noise as high as 116 dB had any influence on the emission of click series or pulsed calls.

Habituation

Of the two species studied, narwhals consistently demonstrated the least sensitivity to ship noise--they were always the last to leave an area during disturbance and the first to return. In 1983 they had returned within 2 h (possibly even earlier) after the end of the first period of disturbance by the Arctic. During the second disturbance period in 1983, which involved both the start-up of the Arctic and the open-water arrival of the MacDonald, narwhals returned to the disturbance area while the latter ship was still operating at a distance of 13 km from the ice edge. Received noise levels attained 120 dB, considerably higher than the sound levels that the narwhals initially responded to. Except for one occasion when the MacDonald returned toward the ice edge to assist the Arctic, we did not discern any notable influence of the ship noise on the distribution and behaviour of narwhals. In fact, they tended to concentrate in the bight created by the ship and much of their diving was directed into the ship track. The resightings of distinctively-marked male narwhals indicate that at least some portion of the ice-edge population continued to return to the disturbance area in spite of previous exposure to ship noise.

Belugas consistently showed much stronger reactions to ship noise; they were displaced farther and they returned to normal patterns of distribution and behaviour more slowly than the narwhal. Almost all ship start-ups evoked some vocal response, although these appeared to grade from 'first-order' alarm signals (e.g., broadband screams) during the initial disturbances to more of the signals (e.g., chirp trains) or signal qualities suggestive of heightened excitement during later disturbances. For example, belugas reacted to the ship start-up in the fifth disturbance period by emitting alarm calls and moving away but they returned to the disturbance area within

1.5 h while the ship was still operating. The maximum received noise levels (112 dB) were much higher than the sound levels that had earlier elicited strong avoidance, although the use of chirp trains suggests that they were either annoyed or excited by the ship noise. It is difficult to determine just when belugas had returned to normal distribution patterns, but it was not until after the sixth disturbance period, when the ships were well into the fast ice, that they fully reoccupied the ice edge around the ship disturbance.

Attraction of Whales to the Ship Track and Ice Cracks

The attraction of narwhals (and to some extent, belugas) to the ship track was probably indicative of exploratory behaviour and the typical strong urge of these whales to move through the ice toward their summering grounds as soon as conditions permit (Finley and Miller 1982; Finley and Gibb 1982). The initial attraction of narwhals to the ship track appeared to wane after they were unable to find access through the rubble-filled track. However, as soon as the ship-induced ice crack formed on 2 July, large numbers of whales moved in and advanced as far as they could. Some whales also appeared in isolated open areas in the ship track but the majority followed the ice crack. This took them within 23 km of the ice-breaking ships.

The sudden movement of large numbers (over 1000) of narwhals (including many females and young) into and toward the ice crack indicated a significant influx (presumably coordinated by acoustic exchange) of whales from offshore areas. Typically, males preceded females and immatures in these movements (Finley and Miller 1982). Up until this time the ice edge had been occupied by a consistently small population (100-200) of adult male narwhals. The general decrease in numbers of narwhals following their movement into the ice crack indicates that they returned to offshore areas after finding their way blocked. It is also possible that the narwhals were able to find an alternate route through ice cracks but we doubt this since we did not see any other major ice cracks and it is likely that any major westward movement of narwhals would have been detected at our camp or by the many parties of Inuit hunters in the area.

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APPENDIX A

Table 1. Band levels vs time, dB//1μPa, 20-1000 Hz.
Ice edge at Lancaster Sound, 20 June - 6 July 1983.

1983 Date	EDT Time	Band levels at depths 3 m	 20 m	Remarks
20 June	14:58		107	Ambient.
	17:12	99	104	Ambient; 1-16 kHz level=91 dB.
21 June	21:02	87	94	Ambient.
22 June	03:03	87	94	Ambient.
	13:02	82	97	Ambient.
	17:15	89	94	Ambient.
	21:01	89	93	Ambient.
23 June	00:05	104	94	Ambient.
	06:01	86	99	Ambient.
	12:03	88	100	Ambient.
	18:03	102	95	Ambient.
24 June	02:02		102	250 km to 'MV Arctic'
	06:01		98	132 km to 'MV Arctic'
	08:02		101	84 km to 'MV Arctic'
	10:00		105	47 km to 'MV Arctic'
	11:00		107	25 km to 'MV Arctic'
	12:07		125	10 km to 'MV Arctic'
	13:05		134	5 km to 'MV Arctic'
	13:13		125	MV Arctic.
	13:14		112	MV Arctic, faint ship sounds.
	13:19		115	MV Arctic, faint ship sounds.
	13:33		115	MV Arctic, reported to be hitting the ice edge at this time.
	14:31		107	Steady ship noise
	14:59		117	Strong ship noise; last data before moving camp.
	22:27		148	Ship in reverse.
	22:30		132	Ship going ahead.
	22:42		136	Reverse, 672 m.
	22:45		130	Ahead.
	23:29		125	Ahead.
	23:33		131	Reverse, 672 m.
25 June	14:00	89	97	Ambient, animal sounds.
	20:00	87	100	Ambient, animal sounds.
26 June	00:01	93	102	Ambient.
	07:59	106	109	Unknown ship engine sounds.
	08:13	111	124	Strong rapping, ship sounds.
	09:52	96	121	Ship sounds.
	10:57	110	121	JAM approaching.
	11:16	109	121	JAM approaching.
	11:17	102	113	JAM approaching.
	11:19	101	114	JAM approaching.
	11:19+	94	105	JAM approaching.
	11:20	102	93	Ambient.

1983	EDT	Band levels at depths		
Date	Time	3 m	20 m	Remarks
	11:43	84	99	Ambient.
	13:15	100	109	JAM range 23 km.
	14:18	101	113	JAM sounds.
	14:21	105	119	JAM in reverse.
	14:25	107	121	JAM, strong ramming sounds.
	14:30	98	110	JAM, strong ramming sounds.
	14:31	108	121	JAM in reverse.
	16:52	111	118	JAM enters track of 'MV Arctic'.
	16:55	118	125	2.8 km to JAM.
	16:56	106	111	JAM propellers slowing.
	16:59	112	115	2.5 km to JAM, drifting.
	18:20	110	122	JAM in reverse.
	18:20+	95	104	Faint ship sounds, seals.
	18:21	93	114	Ships are 13 km distant.
	18:59	89	102	Faint ship sounds.
	19:00	99	112	Ship and bearded seal sounds.
	21:01	105	118	JAM, rumbling ship sounds.
	21:01+	85	95	Animal sounds.
	21:03		108	Faint ship, animal sounds.
	21:09	102	113	JAM, rumbling sound.
	21:10	85	96	Seal and animal sounds.
	22:00	99	111	JAM and seal sounds.
	22:10		120	Steady sound from JAM.
27 June	02:22	100	116	JAM rattling sounds.
	02:23	85	96	Animal sounds.
	02:24	94	108	Intermittent rattling sounds.
	07:02		94	Ambient.
	12:07		102	JAM steady sounds.
	12:08		87	JAM 'galloping' sounds.
	12:09		114	JAM rattling sounds.
	12:11		103	JAM steady sounds.
	12:12		112	JAM rattling sounds.
	12:13		109	JAM galloping/rattling.
	12:14		101	JAM steady.
	18:21		110	JAM intermittent rattling.
	18:21+		115	RAM strong rattling.
	18:40		106	RAM intermittent rattling.
	18:41		108	RAM strong rattling.
	19:04		113	JAM intermittent rattling.
	19:04+		115	JAM strong rattling.
28 June	00:01	104	112	JAM intermittent rattling.
	00:02	108	115	JAM strong rattling.
	00:10	103	111	JAM intermittent rattling.
	00:10+	108	116	JAM strong rattling.
	01:58	106	115	JAM prolonged rattling.
	01:59	108	116	JAM strong prolonged rattling.
	02:05	106	115	JAM prolonged rattling.
	02:06	106	115	JAM prolonged strong rattling.

1983 Date	EDT Time	Band levels at depths 3 m	20 m	Remarks
	08:15	101	102	Animal sounds.
	08:15+	106	111	Ship starting up, animal.
	09:19		116	Strong steady ship sound.
	09:20		107	Faint ship noise, animals.
	10:03		114	Strong rattling ship sound.
	10:04		104	Faint stable ship sound.
	10:11		108	Intermittent rattling.
	10:11+		115	Strong ship rattling sound.
	12:00		113	Steady ship sound.
	12:01		115	Steady ship, faint rumbling.
	12:03		115	Steady ship, faint rattling.
	12:04		113	Steady ship sound.
	12:06		116	Steady ship, faint rattling.
	12:09		115	Steady ship, faint rattling.
	12:10		113	Steady ship sounds.
	20:05		107	Ambient, animal sounds.
29 June	05:58		95	Faint ship sounds, animals.
	06:01		112	Prolonged ship rattling sounds.
	06:03		111	Prolonged rattling ship sounds.
	06:09		111	Ship rattling sound, animals.
	11:50		98	Rhythmic ship sounds, 2 ships.
	11:52		104	Intermittent rattling, 2 ships.
	11:55		106	Rhythmic increase, 2 ships.
	11:56		108	Intermittent rattling, 2 ships.
	11:58		110	Steady ship sound, 2 ships.
	12:00		111	Strong ship sounds, 2 ships.
	12:01		116	Strong rattling, 2 ships.
	12:04		121	Brief strong rapping, 2 ships.
	12:05		117	Brief strong rapping, 2 ships.
	12:31		120	Strong rattling, 2 ships.
	20:10	98	110	Steady ship sound.
	20:11	95	104	Narwhal & animal noises.
	20:16	94	106	Faint rattling and tapping sounds.
	22:56	95	111	Steady ship sounds, animals.
30 June	02:27	88	96	Ambient, animal sounds.
	15:54	102	116	Brief strong ship rattling.
	16:02	125		Strong animal sound, > 600 Hz.
	22:06	99	110	Strong rattling ship sound.
1 July	08:14	100	113	Strong rattling ship, animals.
	08:17	96	106	Steady ship sound, animals.
	20:04	102	115	Brief rattling sound, ship.
	20:09	100	114	Steady ship sound, animals.
2 July	04:02	97	109	Steady ship sound, animals.
	04:07	98	110	Ambient before gunshot.
	04:07+	97	110	Gunshot, animal sounds.
	04:08	95	103	Ambient after gunshot, animals.
	12:09	88	97	Brief, faint ship rattling sound.
	18:03	102	110	Ice ridging and animal sounds.

1983 Date	EDT Time	Band levels at depths 3 m	 20 m	Remarks
3 July	16:17		103	Strong steady sound, 2 ships.
	21:24		110	MV Arctic rattling, 37 km.
4 July	16:13	76	99	Ship rattling sound, animals.
	16:13+	78	104	Steady ship sound, animals.
6 July	14:51	107	108	Skidoo passing by.
	14:51+	107	104	Skidoo passing by.

APPENDIX B

Table 3. One-third octave band levels vs time, dB//1μPa.
The bands extend from 1 to 12.5 kHz, the hydrophone depth was 20 m.
Ice edge at Lancaster Sound, 20 June - 6 July 1983.

1983 Date	EDT Time	Center Frequencies (kHz) of 1/3rd Octave Bands												Wide band
		1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	1-16
20 June	14:58	96	90	89	88	88	91	86	84	82	90	89	85	100
	17:12	85	83	82	81	80	80	80	83	82	76	73	72	91
21 June	21:02	87	88	94	90	91	92	93	93	92	91	92	88	102
22 June	03:03	92	92	91	90	89	90	91	93	89	86	85	85	100
	13:02	82	87	82	85	84	83	76	76	72	73	72	76	92
	17:15	85	82	82	84	82	83	84	84	83	77	74	75	93
	21:01	87	88	87	86	86	87	88	90	87	82	80	83	97
23 June	00:05	91	87	84	84	87	84	88	88	88	83	72	68	96
	06:01	91	91	90	89	88	89	88	87	85	81	79	80	98
	12:03	90	89	88	90	88	85	87	84	83	83	81	80	97
	18:03	79	81	85	79	77	75	74	72	70	66	66	68	88
24 June	02:02	85	85	72	72	72	68	67	63	61	61	61	65	87
	06:01	80	79	81	84	75	72	72	69	65	66	63	65	88
	08:02	82	81	80	79	74	75	73	70	68	67	62	65	87
	10:00	81	83	84	79	78	75	73	71	69	71	68	68	89
	11:00	85	84	83	82	81	80	77	76	74	72	72	73	91
	12:07	109	110	108	108	105	103	100	99	95	92	87	86	115
	13:05	122	122	122	121	119	119	119	113	112	108	104	101	129
	13:13	117	114	111	112	112	107	108	103	101	98	94	91	120
	13:14	105	104	99	100	99	95	91	89	85	82	80	79	109
	13:19	121	120	120	120	120	121	118	112	111	110	103	102	128
	13:33	101	101	103	103	105	102	101	97	91	89	88	89	111
	14:31	97	96	98	99	97	95	92	92	90	89	87	87	105
	14:59	116	119	120	120	119	118	117	115	114	113	110	108	128
	22:27	139	141	140	140	138	135	134	132	130	130	129	128	147
	22:30	126	127	126	127	127	126	126	125	124	124	124	125	136
	22:42	126	127	128	128	127	125	124	122	122	120	119	119	136
	22:45	118	118	119	119	118	116	113	110	109	106	101	99	126
	23:29	111	112	112	111	110	108	108	107	105	105	102	101	120
	23:33	117	119	120	120	118	116	114	115	114	112	113	113	128
25 June	14:00	79	78	77	77	75	74	74	70	65	65	63	66	85
	20:00	85	83	82	82	82	79	78	76	72	67	65	67	90
26 June	00:01	89	87	82	82	82	79	78	79	75	75	72	72	92
	07:59	110	109	110	106	107	106	102	100	97	91	85	82	116
	08:13	114	115	112	109	106	104	100	98	93	87	81	78	119
	09:52	111	111	113	111	113	110	110	107	102	95	90	84	120
	10:57	110	110	109	109	109	106	104	102	96	90	84	79	117
	11:16	112	113	111	110	112	106	102	103	99	90	85	81	119
	11:17	104	105	103	100	102	97	94	95	91	83	77	75	110
	11:19	105	105	102	102	104	99	95	94	93	85	79	74	111

1983	EDT	Center Frequencies (kHz) of 1/3rd Octave Bands												Wide band
Date	Time	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	1-16
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	11:19+	96	97	94	94	96	91	87	87	86	79	73	73	103
	11:20	86	85	93	88	81	78	76	74	72	69	68	72	95
	11:43	82	80	79	77	75	73	71	70	68	65	64	67	86
	13:15	98	95	94	96	91	89	88	86	82	76	69	68	102
	14:16	111	108	112	107	103	101	98	98	96	91	84	81	116
	14:18	99	96	100	95	90	89	87	86	84	78	73	72	104
	14:21	108	105	108	102	96	95	94	92	92	88	80	79	112
	14:30	102	104	108	104	96	93	92	93	95	86	80	83	111
	14:31	111	111	114	111	104	102	100	100	101	94	87	84	118
	16:52	103	100	102	103	102	102	99	100	97	95	95	94	111
	16:55	103	101	102	102	102	100	99	98	96	96	95	95	110
	16:56	94	94	94	95	94	93	92	89	87	86	86	86	102
	16:59	101	101	101	101	100	100	98	96	96	97	94	97	110
	18:20	108	109	110	105	105	102	97	96	91	84	77	76	115
	18:20+	87	85	84	82	82	79	77	74	72	68	68	69	91
	18:21	94	94	93	88	88	87	83	82	78	73	71	70	99
	18:59	89	84	83	82	80	78	79	76	73	70	69	71	91
	19:00	94	89	87	86	83	80	79	77	74	71	70	72	95
	21:01	106	110	110	107	104	102	100	96	93	87	79	77	115
	21:01+	85	82	81	82	82	82	84	83	77	74	71	73	92
	21:03	89	88	85	85	83	83	86	84	78	75	71	74	94
	21:09	100	97	96	96	93	91	90	88	85	80	75	79	104
	21:10	82	82	82	83	81	83	86	84	80	76	72	75	92
	22:00	102	100	98	97	95	92	91	88	85	80	78	77	106
	22:10	113	113	107	108	107	102	101	99	94	88	83	80	117
27 June	02:22	105	104	108	104	100	97	94	91	86	78	73	75	112
	02:23	85	82	82	81	79	78	78	75	74	72	71	73	90
	02:24	100	93	98	92	92	92	85	80	75	71	71	73	103
	07:02	87	84	84	85	85	82	82	82	81	76	72	71	93
	12:07	94	92	86	88	86	84	82	77	74	68	64	65	96
	12:08	97	98	90	89	89	85	83	79	76	70	66	69	101
	12:09	108	109	105	104	102	100	97	93	88	81	72	70	113
	12:11	91	89	84	82	81	81	81	79	74	68	65	67	94
	12:12	105	108	102	104	101	98	95	92	86	80	70	69	111
	12:13	104	103	97	96	93	88	86	82	76	69	66	69	106
	12:14	92	91	86	86	85	83	81	79	76	69	65	66	95
	18:21	103	97	92	92	91	92	94	91	90	84	80	81	104
	18:21+	107	106	103	101	98	96	95	93	90	84	81	82	110
	18:40	91	93	92	92	90	92	94	94	90	85	80	82	102
	18:41	102	103	101	98	96	95	94	93	89	84	81	83	108
	19:04	95	94	92	92	91	91	93	95	89	85	80	82	102
	19:04+	105	103	102	104	101	99	97	96	92	86	82	82	110
28 June	00:01	99	103	103	97	100	99	100	96	98	95	94	95	110
	00:02	105	104	102	100	97	97	96	98	98	95	95	95	110
	00:10	101	100	97	95	93	92	90	90	88	91	85	89	105
	00:10+	105	104	102	100	98	97	94	94	89	91	88	92	110
	01:58	101	98	95	94	91	91	92	89	86	82	80	80	104
	01:59	105	104	99	99	96	93	92	89	88	81	78	82	108

1983	EDT	Center Frequencies (kHz) of 1/3rd Octave Bands												Wide band
Date	Time	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	1-16
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	02:05	100	97	94	93	90	88	88	88	90	81	78	81	103
	02:06	100	98	96	94	92	91	90	89	88	82	82	87	104
	08:15	91	96	97	91	90	88	91	92	89	88	80	81	102
	08:15+	92	93	94	90	92	88	86	85	84	85	77	77	100
	09:19	105	104	101	99	97	95	92	89	85	82	80	81	108
	09:20	94	92	91	89	88	87	86	84	82	81	80	80	98
	10:03	102	99	99	97	94	90	88	84	82	79	78	79	105
	10:04	90	89	88	87	86	84	84	82	80	79	78	78	96
	10:11	94	91	89	88	86	85	84	82	81	79	79	80	97
	10:11+	103	100	99	98	94	92	88	86	82	80	79	80	106
	12:00	104	104	105	102	100	102	98	94	94	89	84	80	111
	12:01	103	103	105	101	98	101	98	94	93	89	84	80	110
	12:03	107	107	108	105	102	106	105	104	101	92	82	76	115
	12:04	103	104	105	102	98	101	98	94	93	89	84	80	110
	12:06	103	104	104	102	98	101	97	94	92	89	84	79	110
	12:09	103	103	105	102	99	102	97	94	93	89	84	80	110
	12:10	103	103	104	102	99	102	96	94	92	89	83	79	110
	20:05	85	86	83	82	80	82	83	84	82	75	72	72	93
29 June	05:58	83	84	83	83	82	82	83	82	81	76	74	78	92
	06:01	92	91	91	92	87	92	85	87	84	85	84	89	100
	06:03	95	94	93	91	89	88	91	87	84	85	85	83	101
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	11:52	95	94	92	90	88	86	84	80	75	71	67	70	99
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	11:58	99	98	93	92	93	88	88	81	78	73	69	71	102
	12:00	102	102	98	98	98	90	92	84	82	75	70	71	107
	12:01	109	109	104	104	103	97	97	91	88	82	76	74	113
	12:04	117	115	110	112	111	104	104	99	93	86	80	79	120
	12:05	116	112	109	107	104	100	96	91	86	79	76	80	117
	12:31	113	111	107	106	106	100	98	95	88	82	75	76	115
	20:10	94	93	91	90	89	89	90	91	89	82	79	83	100
	20:11	95	94	97	101	100	97	96	98	97	93	92	92	108
	20:16	91	90	89	89	88	90	92	93	92	84	81	84	100
	22:56	98	96	93	91	90	93	92	96	94	86	84	88	104
30 June	02:27	90	91	90	89	93	91	91	91	88	84	84	85	100
	15:54	111	125	126	130	119	116	123	118	120	116	108	104	134
	16:02	[not avail at 20 m]												
	22:06	102	97	97	96	92	91	91	91	90	84	83	86	105
1 July	08:14	91	88	87	88	90	89	87	87	84	77	75	81	97
	08:17	97	94	91	91	89	90	89	91	86	82	75	77	101
	20:04	99	97	93	90	87	83	82	79	78	75	73	72	101
	20:09	98	97	93	92	90	89	88	97	93	89	86	82	103
2 July	04:02	96	94	94	97	96	98	97	95	92	89	86	90	105
	04:07	96	95	95	96	97	98	98	96	94	89	87	88	106
	04:07+	95	94	93	93	94	98	100	99	97	93	87	86	106
	04:08	98	97	97	101	102	102	100	99	96	93	94	95	110

1983 Date	EDT Time	Center Frequencies (kHz) of 1/3rd Octave Bands												Wide band
		1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	1-16
	12:09	85	84	84	83	81	79	82	76	75	73	72	75	91
	18:03	104	105	111	105	105	103	102	101	102	103	100	102	116
3 July	16:17	108	103	102	101	100	100	103	101	98	92	88	88	111
	21:24	102	99	95	94	95	90	89	88	83	78	76	78	104
4 July	16:13	88	86	86	86	88	91	92	88	85	86	84	80	98
	16:13+	90	88	86	88	92	92	91	85	84	80	80	81	99
6 July	14:51	91	91	90	92	91	89	88	89	88	84	82	84	100
	14:51+	92	92	92	92	91	91	90	90	88	85	83	82	100

Section 4

Report of 1984 Study

DISTRIBUTION AND MOVEMENTS OF NARWHALS AND BELUGA WHALES IN RESPONSE TO SHIP TRAFFIC AT THE LANCASTER SOUND ICE EDGE - 1984

by
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for
Northern Environmental Protection Branch
Canada Dept. of Indian Affairs and Northern Development
Ottawa, Ontario

November 1984

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ACKNOWLEDGEMENTS

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We thank C.R. Evans of LGL Ltd. for his assistance with the field work and data analysis and K.J. Finley, also of LGL Ltd., for reviewing the report and contributing to the study. B. De Long drafted the figures and B. Griffen typed the report.

INTRODUCTION

In 1982 and 1983, DIAND and several industrial concerns and government agencies sponsored studies of the potential effects of arctic marine shipping on narwhals and belugas in the Lancaster Sound region. These studies examined the behavioural and acoustical responses of whales to the approach, and ice-breaking activities, of the cargo vessel MV Arctic and (in 1983) the icebreaker CCGS John A. MacDonald.

In both years major changes in whale distribution occurred in response to the activities of the icebreaking vessels. However, for various reasons these distributional responses could not be fully documented. In 1982, whale distribution could only be assessed during infrequent periods when helicopter support was available. The distributional response of whales to the arrival of the MV Arctic at the Admiralty Inlet ice edge could not be determined until 28 and 52 hours after the ship arrived and began breaking ice. In 1983, a helicopter was dedicated to the study but poor weather made it impossible to conduct aerial surveys during the critical period of the arrival of the MV Arctic at the Lancaster Sound ice edge.

In 1984, as a supplement to the 1982 and 1983 studies, a program of aerial surveys was conducted at the Lancaster Sound ice edge, specifically to examine the immediate distributional responses of narwhals and belugas to arctic marine shipping. The brief (1 week) study was designed to document whale distribution at the Lancaster Sound ice edge before, during, and after the expected approach and passage of the MV Arctic and CCGS Louis St. Laurent into and through the ice en route to the Nanisivik Mine in late June and early July. The objectives of the surveys were to provide better documentation of the distribution and movement patterns of whales in response to ship traffic and to determine whether the responses were qualitatively similar over the three years of study.

The present report gives the results of the 1984 surveys and provides some comparison with the surveys from previous years. However, the reader will have to refer to the following reports of the 1982 and 1983 studies for full details of the surveys in those years:

Finley, K.J., C.R. Greene and R.A. Davis. 1983. A study of ambient noise, ship noise, and the reactions of narwhals and belugas to the MV Arctic breaking ice in Admiralty Inlet, N.W.T. - 1982. Rep. by LGL Limited, Toronto, for Canada Department of Indian Affairs and Northern Development, Ottawa. 108 p.

Finley, K.J., G.W. Miller, R.A. Davis and C.R. Greene. 1984. Responses of narwhals (Monodon monoceros) and belugas (Delphinapterus leucas) to ice-breaking ships in Lancaster Sound - 1983. Rep. by LGL Ltd., King City, Ontario, for Canada Department of Indian Affairs and Northern Development, Ottawa. 117 p.

The results and major conclusions of the three year study are combined and integrated in an overview report:

Finley, K.J. and R.A. Davis. 1984. Reactions of beluga whales and narwhals to ship traffic and ice-breaking along ice edges in the eastern Canadian High Arctic: 1982-1984. An overview. Rep. by LGL Limited, King City, Ontario, for Canada Department of Indian Affairs and Northern Development, Ottawa. 42 p.

METHODS

Study Design

In late June 1984, the Lancaster Sound ice edge extended north from Cape Charles Yorke on Baffin Island to a point 8 km west of Dundas Harbour on Devon Island (Fig. 1). West of that ice edge, the fast ice over Lancaster Sound was solid and unbroken. LANDSAT imagery from 20 June (one week before the surveys began) showed a clean ice edge with little pack ice except for four very large (5-25 km diameter) pans of ice that had broken off the edge and drifted 20-30 km to the east.

The aerial survey design consisted of two transects flown parallel to the ice edge, one about 400 m east of the edge and one 5 km east of the edge. In addition to these lines, four shorter transect lines were flown in the area offshore from where the icebreaking ships were expected to enter the ice; these four lines were parallel to the southern third of the ice edge and spaced 5 km apart (see Fig. 2). These four southeastern transects were included to determine whether whales move offshore in response to ice-breaking and disturbance at the ice edge.

Survey Procedures

The survey aircraft was a de Havilland Twin Otter equipped with a GNS-500A navigation system for accurate navigation along offshore transect lines, and a radar altimeter for accurate maintenance of the survey altitude. The surveys were flown at an altitude of 152 m (500 ft) ASL and a ground speed of 204 km/h (110 kt).

One observer occupied the co-pilot's seat (front right) and the other occupied the second seat behind the pilot (left side). The observers recorded numbers of marine mammals and their behaviour and direction of movement onto audio tapes.

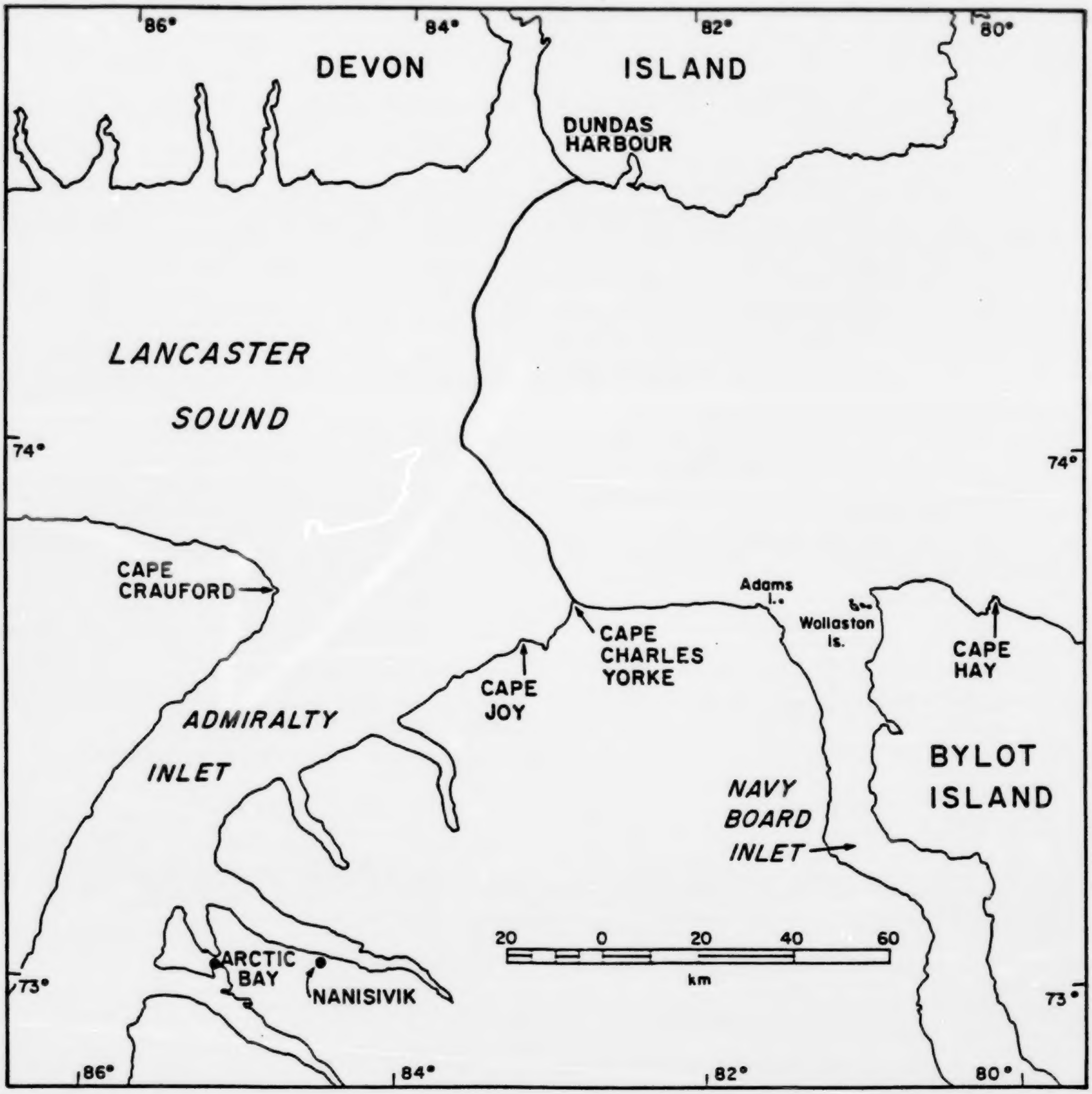

86°
84°
82°
80°
DEVON
ISLAND
DUNDAS
HARBOUR
LANCASTER
SOUND
74°
74°
CAPE
CRAUFORD
Adams
I.
Wollaston
Is.
CAPE
CHARLES
YORKE
CAPE
JOY
CAPE
HAY
ADMIRALTY
INLET
BYLOT
ISLAND
NAVY
BOARD
INLET
20
0
20
40
60
km
ARCTIC
BAY
NANISIVIK
73°
73°
86°
84°
82°
80°

Figure 1. Map of the study area showing the position of the Lancaster Sound ice edge in late June and early July, 1984.

An 800 m wide transect strip on each side of the aircraft was used. The combined total transect width was 1600 m. However, the ice edge transect was flown only 400 m off the ice edge so the effective combined transect width on that transect was only 1200 m.

The observers used inclinometers to determine the angle of depression of the line to the animal when it was directly to the side of the aircraft. Lateral distances of whales from the centre of the transect were later calculated using the sighting angle and aircraft elevation. This ensured that on- and off-transect whales were accurately distinguished, and provided data on the probability of detection of whales across the transect strip. (The observers on the ice-edge side of the ice-edge transect did not use an inclinometer since all sightings were within 400 m of the centre of the transect.)

Position along the transect route was interpolated by the use of an interval timer system, digital watches, and the aircraft's navigation system. The timer was reset to zero at the start of each transect and, thereafter, at 1-min intervals, it produced a sound audible to the observers. This division of transects into 1-min transect segments permitted the mapping of distributions and ice conditions. In one minute at the standard survey speed of 110 kt, the aircraft travelled 1.8 n.mi. or 3.4 km. Given the combined transect width of 1600 m, we surveyed 5.4 km^2 per min of offshore (non-ice edge) transect. During all surveys, parameters of habitat (percentage ice cover, ice type), weather (fog, rain, snow), and sea state (Beaufort Scale) were recorded for each transect segment.

Data Presentation

The distributions of narwhals and belugas observed during aerial surveys have been depicted (Figs. 2-9) by symbols indicating the number of whales observed in each 1-min time period. Increasingly larger symbols (circles for belugas and squares for narwhals) indicate 1-5, 6-15, 16-50, 51-150 and more than 150 whales per time period. (The numbers of whales recorded by the two observers were combined to arrive at the number of whales per time period depicted in the figures.)

Movements of whales have also been represented in these figures. "Major" movements were indicated when more than 75% of the whales observed during a time period were moving in a given direction, except for the 1-5 whales per time period category. When only 1-5 whales were recorded in a time period, 50% or more of the whales moving in a given direction constituted a "major" movement. "Minor" movements were indicated when between 25 and 75% of the whales were moving in a given direction, except in the case of the smallest symbol used (1-5 whales) when less than 50% of the whales moving in a given direction constituted a "minor" movement. When more than 50% of the whales were not showing directed movement the whales were considered to be "milling". Because of their small size, symbols used to indicate major, minor and milling movements for the group size category 1-5 are slightly different from those used for the four larger size categories (see figure legend for examples).

RESULTS

Pre-Disturbance Period, 27 June 1984

The pre-disturbance aerial survey was begun at 11:30, 18.5 h prior to the arrival of the MV Arctic at the Lancaster Sound ice edge. At 12:00, the MV Arctic and CCGS Louis St. Laurent were reported to be at 76°08'N, 81°59'W (pers. comm., Ice Forecasting Central, Ottawa), approximately 40 km west of Coburg Island, and north of Devon Island; this location was over 300 km from their eventual point of entry into the Lancaster Sound ice edge.

A total of 442 narwhals and 2069 belugas were recorded during the survey. The majority of the narwhals and belugas recorded (77% and 84%, respectively) were seen along the ice edge portion of the survey (Fig. 2). The narwhals recorded along the ice edge were concentrated along the southern portion of the ice edge while the belugas were fairly evenly distributed along the entire ice edge. These distribution patterns are consistent with those observed along the ice edge during the pre-disturbance phase of the 1983 study.

Relatively few narwhals were seen on the transects flown offshore from the ice edge. Only 16 narwhals were recorded on the transect paralleling, but 5 km off, the ice edge. All but one of these animals were recorded in the southern half of the transect. A total of 86 narwhals were recorded on the four easternmost transects. Nearly all of these sightings were also recorded in the southern or coastal portions of these transects.

Belugas recorded on the transect 5 km east of, and paralleling, the ice edge were concentrated at either end of the transect, but a few belugas were also seen along the middle portions of the transect. Belugas seen on the two westernmost of the four short transects were concentrated along the southern (coastal) portions of these transects, but this tendency was not apparent on surveys of the two easternmost short transects.

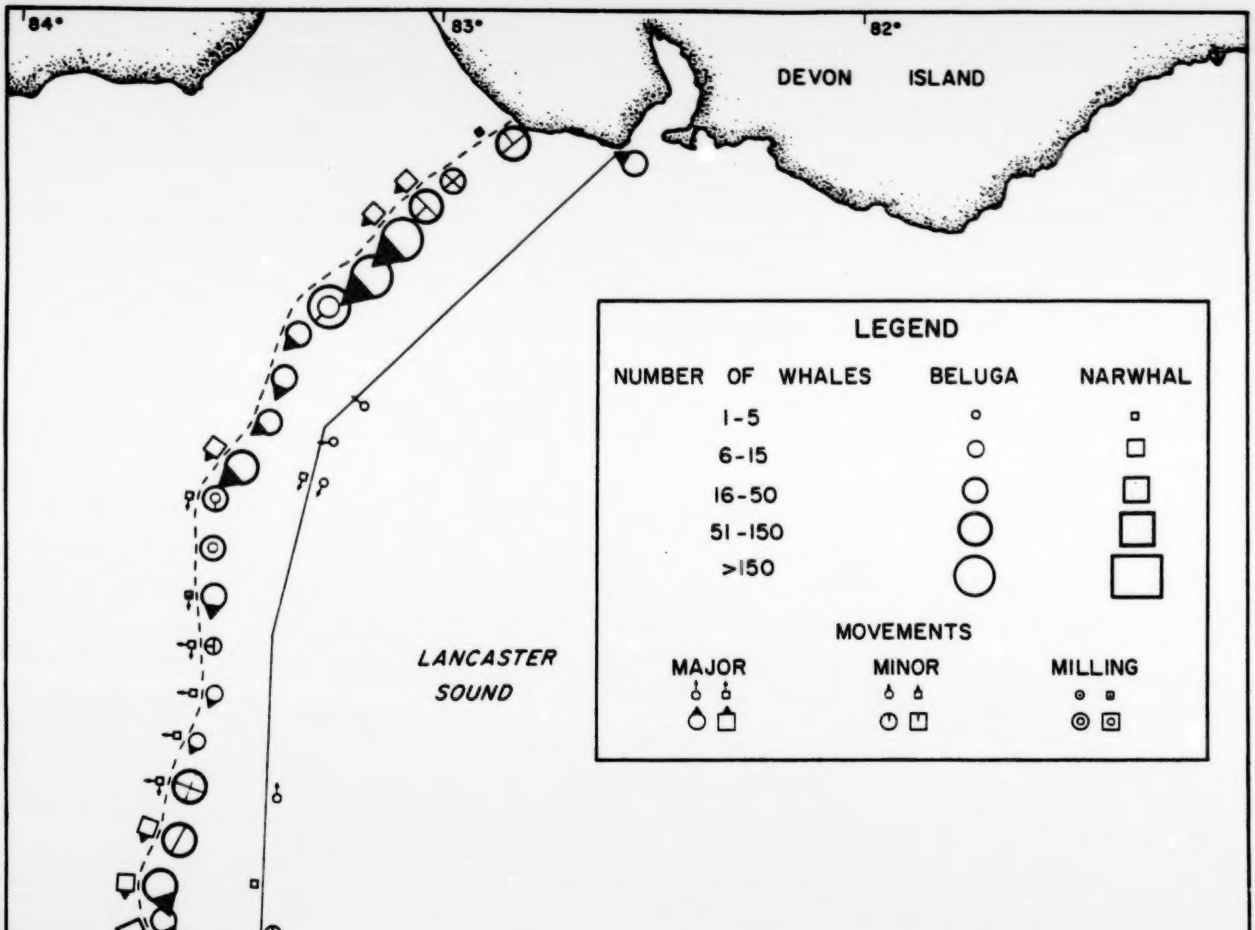

84°
83°
82°
DEVON ISLAND
LEGEND
NUMBER OF WHALES
BELUGA
NARWHAL
1-5
6-15
16-50
51-150
>150
MOVEMENTS
MAJOR
MINOR
MILLING
LANCASTER SOUND
74°
74°
Cape Charles Yorke
5
0
5
10
15
20
25
30
km
BAFFIN ISLAND
83°
82°

Figure 2. Distribution and directions of movement of narwhals and belugas recorded during survey 1, 27 June 1984 (11:30-14:15).

Most of the narwhals and belugas seen along the ice edge were travelling south along the ice edge. Of the narwhals (328) whose directions of movement along the ice edge were recorded, 90% were moving south. The comparable figure for belugas was 80% (n = 1687).

Movements of both species were leisurely and unhurried. A substantial number of belugas (190) were milling or circling near the ice edge. Some playful activities (e.g., belugas swimming on their sides with their flippers out of the water) were observed.

Movements of narwhals and belugas recorded on transects east of the ice edge appeared to be random, with no apparent pattern or preferred direction of movement.

Primary Disturbance Period, 28-29 June 1984

Survey 2, 28 June (a.m.)

The MV Arctic arrived near the Lancaster Sound ice edge at 06:00 on 28 June. Its arrival was followed about 3 h later (09:00) by the arrival of the CCGS Louis St. Laurent. The first disturbance period aerial survey began at 08:00 and continued until 10:00. The Louis St. Laurent arrived in the study area while the survey was in progress. The Arctic was about 2 km east of the ice edge when the survey began (Fig. 3).

A total of 408 narwhals and 3123 belugas were recorded during Survey 2. The number of narwhals recorded (408) was similar to the number seen during the previous survey (442), but a smaller proportion were recorded along the ice edge (77% on 27 June vs. 55% on 28 June). There was a portion of the ice edge near the Arctic where very few narwhals and no belugas were seen (Fig. 3). This barren segment was about 27 km long. No such gaps in beluga distribution had been observed during the previous survey and this gap was along the portion of the ice edge where narwhals had been most concentrated the previous day (Fig. 2). Four narwhals were recorded in this ice edge segment; they were located along the portion of the ice edge closest to the Arctic. One of the narwhals was recorded 1 km off the ice edge, heading

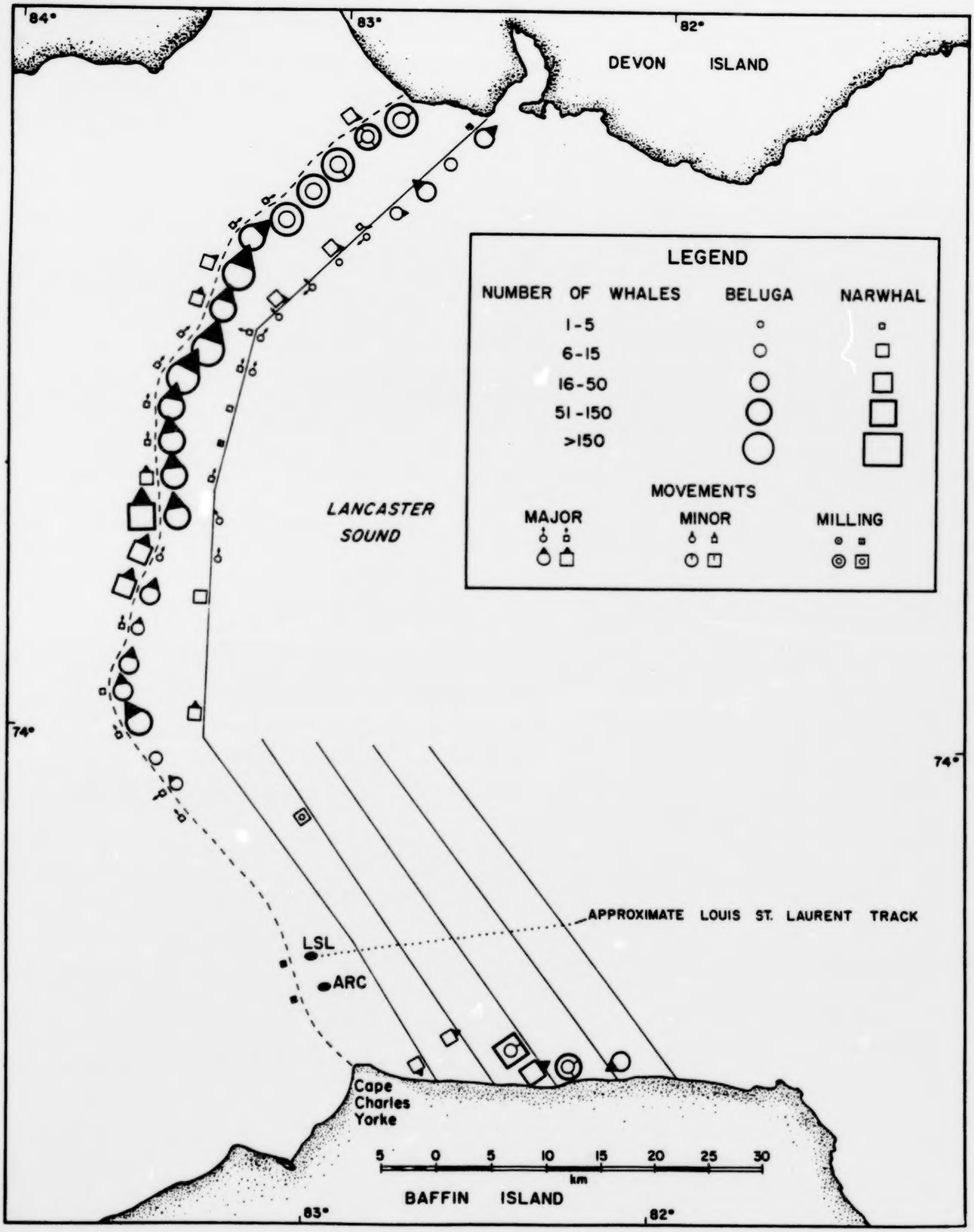

84°
83°
82°
DEVON ISLAND
LEGEND
NUMBER OF WHALES
BELUGA
NARWHAL
1-5
6-15
16-50
51-150
>150
MOVEMENTS
MAJOR
MINOR
MILLING
LANCASTER SOUND
74°
74°
APPROXIMATE LOUIS ST. LAURENT TRACK
LSL
ARC
Cape Charles Yorke
5 0 5 10 15 20 25 30
km
BAFFIN ISLAND
83°
82°

Figure 3. Distribution and directions of movement of narwhals and belugas recorded during survey 2, 28 June 1984 (08:00-10:00). The positions of the MV Arctic (ARC) and CCGS Louis St. Laurent (LSL) at the time of the survey are also indicated.

northward toward the ice edge. Three others were motionless very close to the ice edge. They were about 2 km south of some hunters who were present at the ice edge. These whales may have been "trapped" between the Arctic and the hunting camp to the north. The potential effects of hunting on whale distribution patterns are addressed in the Discussion.

Along the ice edge the closest belugas to the Arctic were about 20 km north of the ship and were moving strongly north along the edge. Virtually all whales encountered for the next 60 km were moving strongly north. Along the northernmost 20 km of the ice edge some whales were moving north, but most were milling and circling near the ice edge.

A total of 67 narwhals were recorded on the transect 5 km east of the ice edge. All of these narwhals were in the northern 2/3 of the transect in contrast to the distribution observed on the previous day, when most sightings were recorded in the southern half of the transect (Fig. 2). The number of narwhals recorded on this transect (67) was higher than the number recorded the previous day (16). The number seen along the ice edge (226) was lower than the number seen along the ice edge on the previous day (340). Thus, it seems possible that there was a net movement of narwhals away from the ice edge into offshore waters in response to the arrival of the Arctic and the approach of the Louis St. Laurent. In support of this suggestion, 25 of 220 narwhals (whose direction of movement was recorded) along the ice edge were moving northeast, east or southeast away from the edge. Whales recorded on the offshore transect parallel to the ice edge were moving north or northeast (66%, n = 56) or were not moving (18%).

Belugas observed on the transect 5 km east of the ice edge were also concentrated in the northern portion of the transect, especially near the Devon Island coast. The number of belugas (82) recorded on this transect was lower than the number recorded the previous day (158). This may be because they were displaced from the southern half of the transect by the recent arrival of the Louis St. Laurent. Most (60%) of the 66 belugas whose directions of movement were recorded were moving north, toward the Devon coast.

Sightings of narwhals and belugas on the remaining transects were strongly concentrated along the coastal portions of the transects. Nearly all (93%) of the 115 narwhals and all 177 belugas recorded on these transects were seen within 7 km of the coast. These surveys were flown immediately after the Louis St. Laurent passed through the area, about 13 km north of the Baffin coast.

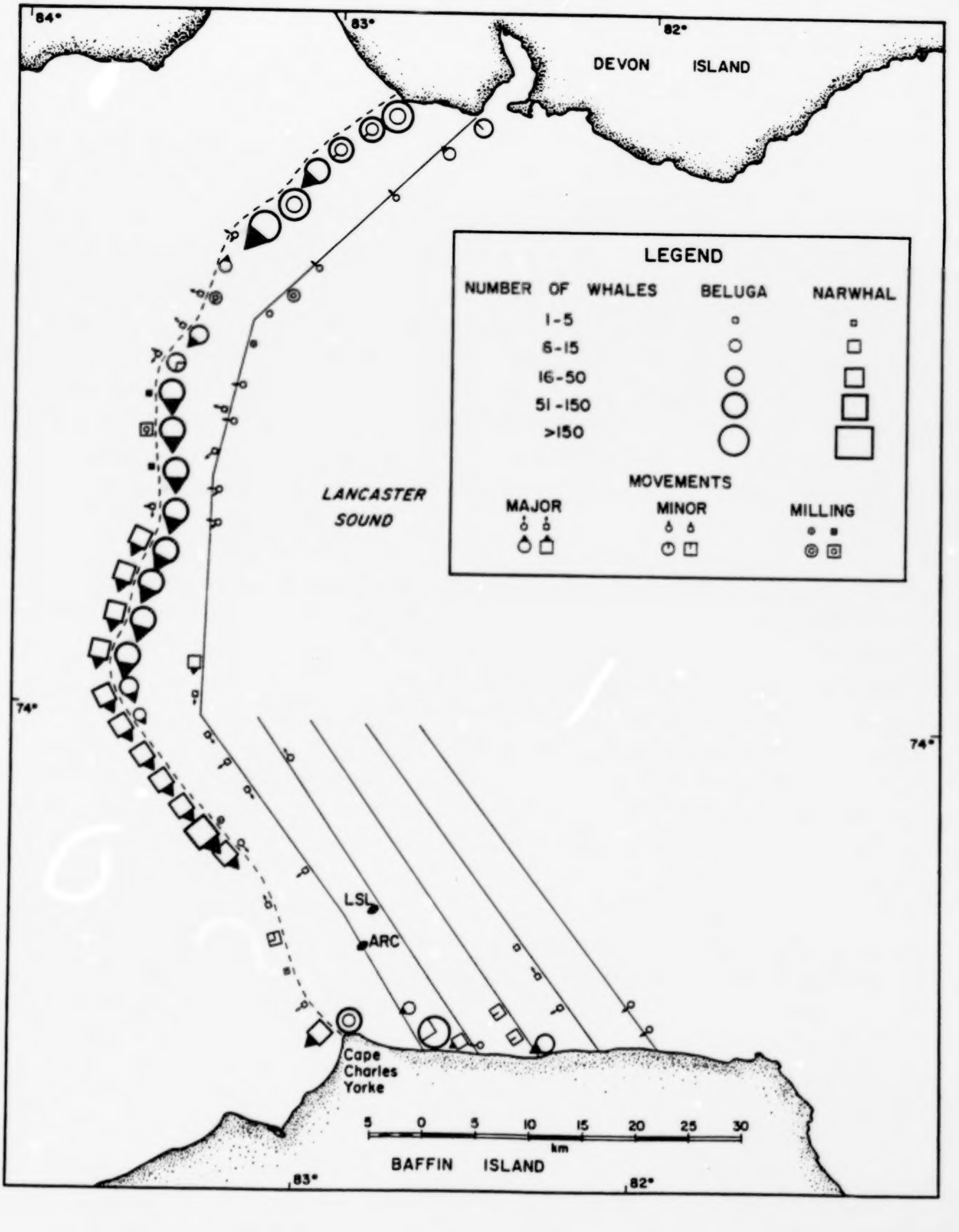
Survey 3, 28 June (p.m.)

The third survey began at 16:00, eight hours after the previous survey. During this period the two ships had remained drifting stationary near (about 5-10 km) the ice edge. The idle ships would have been generating some underwater noise from onboard machinery. A total of 561 narwhals and 2620 belugas were recorded during the survey.

The distribution of whales along the ice edge was beginning to return to the pre-disturbance pattern (Fig. 4). Narwhals were found along the portion of the ice edge that had been vacant earlier in the day. Although most narwhals remained north of the area around the ships, the vast majority (84%) of the 493 narwhals whose directions of movement were recorded were moving south along the ice edge. Another 12% (57 of 493) were moving west toward the edge.

A large gap in beluga distribution still existed in the vicinity of the ships (Fig. 4) but 91% (n = 798) of the belugas in the 70 km section of the ice edge north of the Louis St. Laurent were moving south. North of that segment some belugas were still moving south but most were milling near the edge.

A total of 29 narwhals were recorded on the transect 5 km east of the ice edge. These whales were seen along the central and southern portions of the transect, in contrast to the morning's survey and 85% of the 26 narwhals whose direction of movement was recorded were moving toward the west, southwest, or south, apparently returning to the areas that had been occupied on 27 June. Belugas were still concentrated in coastal portions of this transect but some individuals were seen in offshore portions of the transect. A total of 235 were recorded.


84°
83°
82°
DEVON ISLAND
LEGEND
NUMBER OF WHALES
BELUGA
NARWHAL
1-5
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MOVEMENTS
MAJOR
MINOR
MILLING
LANCASTER SOUND
74°
74°
LSL
ARC
Cape Charles Yorke
5 0 5 10 15 20 25 30
km
BAFFIN ISLAND
83°
82°

Figure 4. Distribution and directions of movement of narwhals and belugas recorded during survey 3, 28 June 1984 (16:00-18:00). The positions of the MV Arctic (ARC) and CCGS Louis St. Laurent (LSL) at the time of the survey are also indicated.

A total of 32 narwhals and 53 belugas were recorded on the remaining eastern transects. Nearly all of the sightings occurred along the coastal portions of these transects.

Survey 4, 29 June (a.m.)

The two ships had moved north along the ice edge (about 15 km) and pushed their way a short distance into the ice, about 20 km northwest of Cape Charles Yorke, at 19:00 on 28 June. They remained there side by side throughout the night. This was the position they maintained throughout the survey. The aerial survey began at 08:10, about 26 h after the arrival of the Arctic at the ice edge and 23 h after the arrival of the Louis St. Laurent. Overall, 393 narwhals and 2649 belugas were recorded during Survey 4 (Fig. 5).

Narwhals, which had been observed moving south during the previous survey (Fig. 4), were now concentrated along the southern portion of the ice edge in a distribution very similar to that observed during the pre-disturbance survey (Fig. 2). The distribution of narwhals did not indicate that the animals were actively avoiding the ships (Fig. 5). During the survey we had radio reports from the Louis St. Laurent that three narwhals were seen from the stern of the ship. Narwhals seen along the southern portion of the ice edge were moving in various directions, but most of those seen along the northern half of the ice edge were moving south along the edge.

Belugas were still absent from a 17 km long section of the ice edge south and immediately north of the ships, but the length of this section had decreased from about 34 km during the previous survey. Belugas north of this avoidance zone were milling or resting (43% of 2216), moving south along the edge (33%), or moving in other directions (24%).

Thirty-four narwhals were seen along the transect 5 km east of the ice edge. The distribution of these sightings was similar to that observed during the pre-disturbance survey, with most animals on the southern half of the transect. A total of 200 belugas were recorded along this transect. In

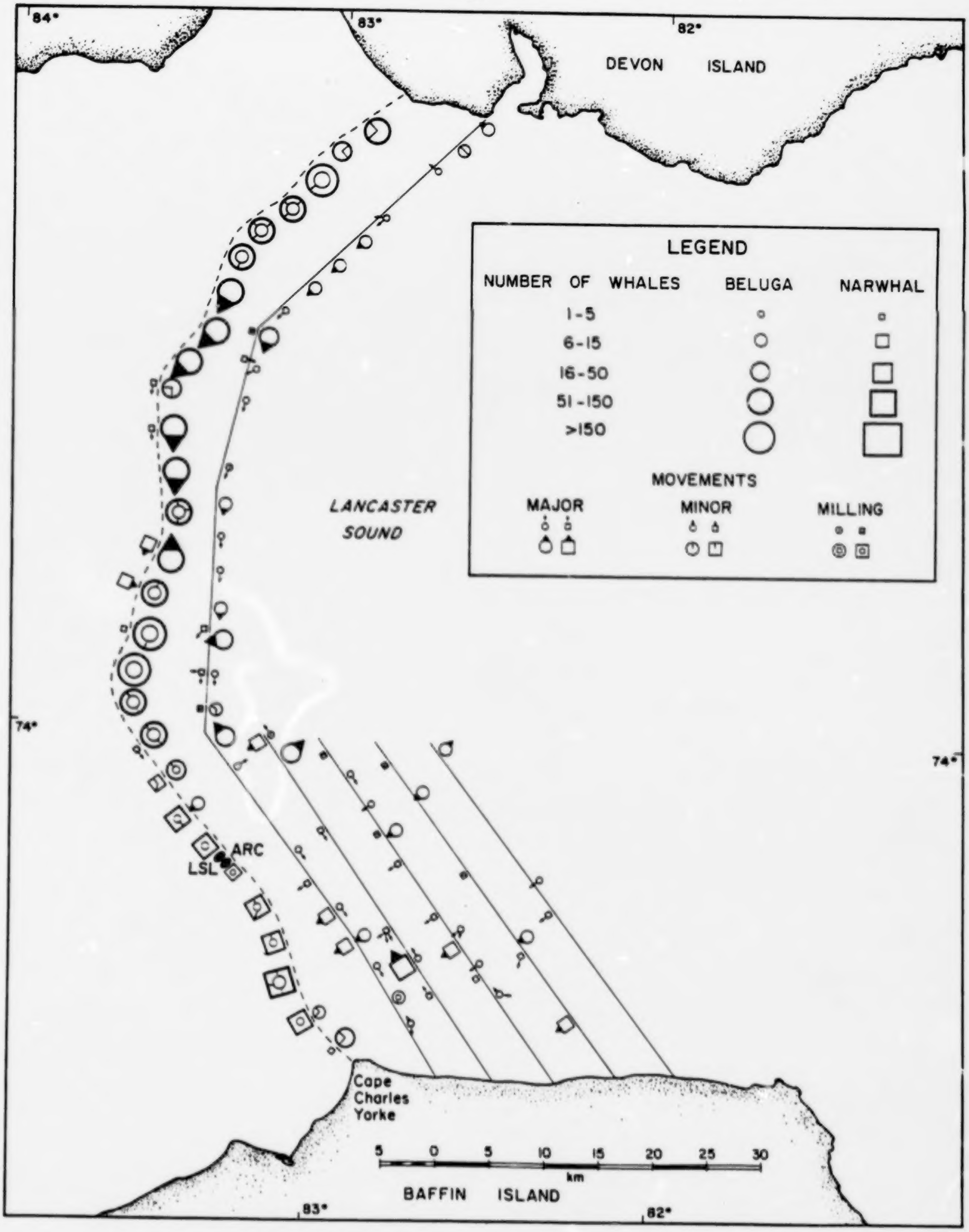

84°
83°
82°
DEVON ISLAND
LEGEND
NUMBER OF WHALES
BELUGA
NARWHAL
1-5
6-15
16-50
51-150
>150
MOVEMENTS
MAJOR
MINOR
MILLING
LANCASTER SOUND
74°
74°
ARC
LSL
Cape Charles Yorke
5
0
5
10
15
20
25
30
km
BAFFIN ISLAND
83°
82°

Figure 5. Distribution and directions of movement of narwhals and belugas recorded during survey 4, 29 June 1984 (08:10-10:15). The positions of the MV Arctic (ARC) and CCGS Louis St. Laurent (LSL) at the time of the survey are also indicated.

contrast to all previous surveys, a substantial number of these sightings occurred on offshore portions of the transect rather than being concentrated at the two coastal ends of the transect. Most (71%) of the 193 belugas whose direction was recorded were moving toward the south, southwest, or west. This movement may represent the return of belugas that had been displaced to the north by the arrival of the ships the previous morning.

A total of 86 narwhals were recorded on the four eastern transects. These whales were widely distributed along the length of these transects. In contrast, during the previous two surveys most of the narwhals were seen along the coastal segments of these transects. This distribution pattern was most similar to the distribution seen during the pre-disturbance survey. Narwhals were recorded moving in various directions but many (42%) were moving toward the southwest.

The distribution of the 120 belugas recorded on the four eastern transects was similar to the distribution of narwhals. Belugas were seen well offshore along these transects and no concentrations were observed along the coast. This distribution was also similar to that seen on these transects during the pre-disturbance survey. Belugas sighted along these transects were moving in all directions but more were moving toward the northeast (50%) and southwest (37%) than in any other directions.

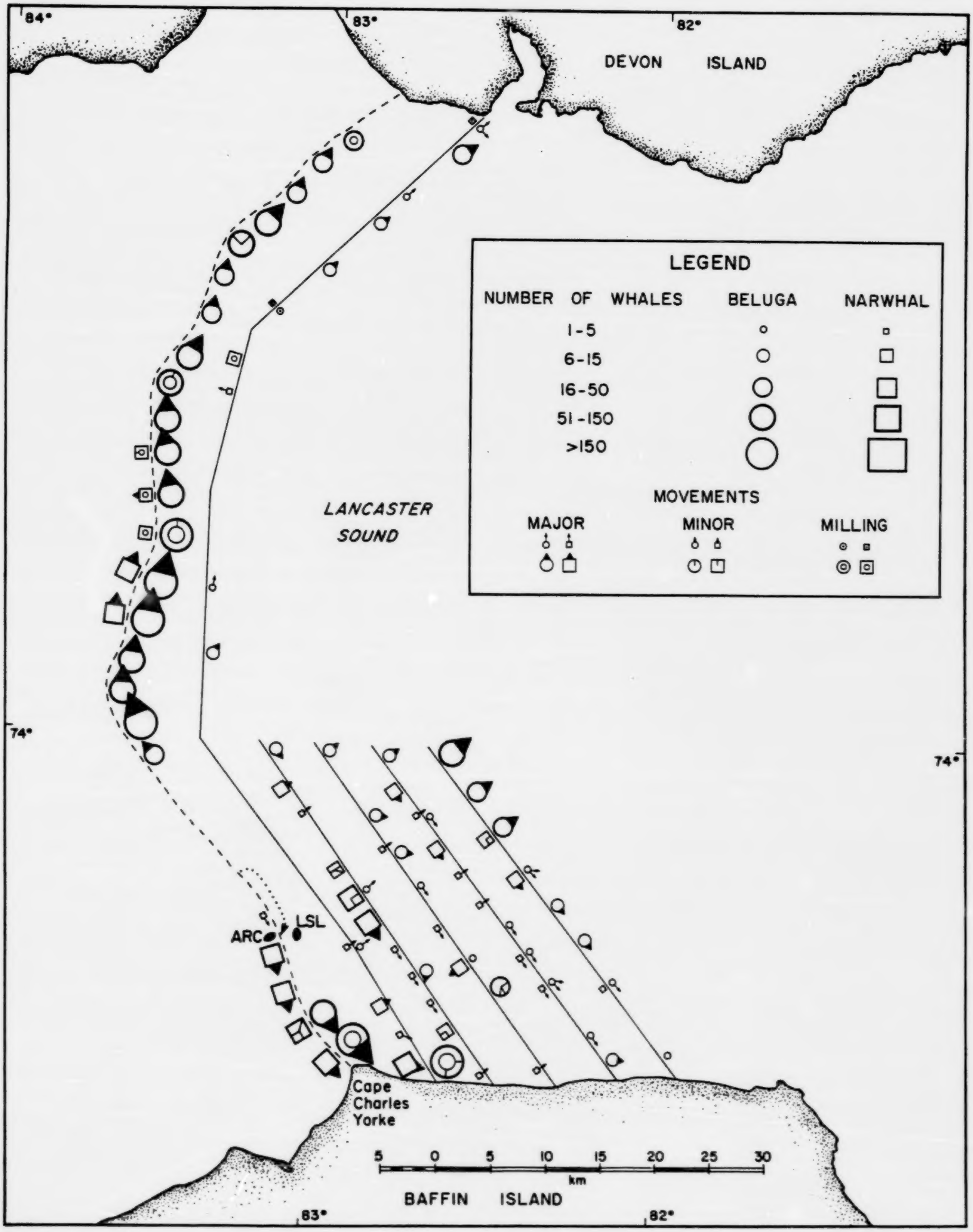
Survey 5, 29 June (p.m.)

When we arrived at the ice edge at 18:30 the two ships were still nestled into the ice about 20 km northwest of Cape Charles Yorke. The Louis St. Laurent reported by radio that the Arctic had started its main engines at 18:00 and that they were planning to begin breaking ice. The transects were flown in reverse order, from east to west, so that we would be able to observe the response of the whales at the ice edge some considerable time after the start of the disturbance, and preferably in response to ice-breaking activity. We observed black smoke coming from the stack of the Louis St. Laurent as it backed out of the ice about two minutes after we began surveying the easternmost transect. During the next hour the two ships moved 7 km south along the ice edge. At 19:30 the Arctic began breaking into the fast ice while the Louis St. Laurent remained off the ice edge (Fig. 6). Thus, the entire survey can be considered to have been conducted during ongoing disturbance, although the disturbance ranged during the course of the survey from engine start-up, to movement of the ships, to ice-breaking.

The behavioural response of the whales to the start-up of the ships was evident to both aerial observers shortly into the first (easternmost) offshore transect. Both observers remarked upon the rapid movements of virtually all of the whales recorded on the offshore transects. Whales were porpoising and spending very little time underwater. Belugas appeared to be moving more rapidly than the narwhals, but the increased speed of both species was very apparent compared to rates of movement we had observed during the previous two surveys.

The transect along the ice edge began at 19:20, approximately 80 min after the Arctic reportedly started up. At this time the two ships were still moving south along the ice edge toward the position where they would begin breaking into the fast ice. The distribution of narwhals (Fig. 6) observed during this survey was markedly different from that observed during the survey conducted earlier in the day (Fig. 5). No narwhals were sighted along a 27 km section of the ice edge near the two ships. Narwhals south of the ships were moving south or southeast (87% of 144 narwhals) and those north of the ships were moving north (72% of 93). One pod of five narwhals about 16 km northwest of Cape Charles Yorke was only 300 m southwest of the Arctic at the time we passed the ship. The Arctic (and the narwhals) were moving rapidly to the south at the time.

Belugas also showed a gap in distribution near the ships. However, this gap extended farther south than, and not so far north as, the gap in narwhal distribution (Fig. 6). The zone where no belugas were sighted was only marginally larger than the zone observed during the survey earlier in the day. Belugas south of the ships were moving south (75% of 463 whose direction was recorded) or milling (24%) in the outflow of a river mouth at Cape Yorke. Most belugas north of the ships were moving north (86% of 2649). The southernmost whales that were milling rather than moving were 38 km north of the ship's starting position. Belugas were rapidly departing the disturbance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DEVON ISLAND
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NUMBER OF WHALES
BELUGA
NARWHAL
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MAJOR
MINOR
MILLING
LANCASTER SOUND
74°
74°
ARC
LSL
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5 0 5 10 15 20 25 30
km
BAFFIN ISLAND
83°
82°

Figure 6. Distribution and directions of movement of narwhals and belugas recorded during survey 5, 29 June 1984 (18:30-20:30). The positions of the MV Arctic (ARC) and CCGS Louis St. Laurent (LSL) at the time of the survey are also indicated. The movements of the ships during the survey are indicated by the dotted line.

zone and presumably had been doing so since the Arctic started-up 80 minutes earlier. More belugas (3122) were recorded along the ice edge during the afternoon survey than during the morning survey (2329). A similar increase in numbers was observed between the pre-disturbance survey (1734) and the first disturbance survey (2874) (see Table 1). This apparent increase in numbers is undoubtedly related to the behaviour of belugas in response to recent disturbance. The belugas seen along the ice edge were moving very rapidly, porpoising near or at the surface much of time. They were not diving deep or feeding under the ice edge. Hence, a much higher proportion of the whales are likely to be seen when they are disturbed than when they behave normally. In addition, more belugas may have moved in along the ice edge since the previous survey. Thirty-five percent (41 of 117) of the belugas recorded on the four eastern transects during the previous survey were moving southwest, toward the ice edge.

Most of the 43 narwhals recorded on the transect 5 km east of the ice edge were concentrated near the southern end of the transect. These whales were moving strongly to the northeast and east, directly away from the ice edge. Most (72%) of the 11 narwhals seen along the northern third of the transect showed little directional tendency and were milling or motionless. Belugas were concentrated at the southern end of the transect. Of the 226 recorded on the transect, 175 (77%) were milling near the Baffin coast. The 41 belugas seen along the northern one-third of the transect were heading toward the Devon Island coast.

Large numbers of narwhals (160) and belugas (245) were seen on the four eastern transects. Movements were divided between whales moving directly away from the edge (to the northeast) and those moving southeast toward the Baffin coast. There appeared to be a general tendency for whales at the northern ends of the transects (and closer to the disturbance) to be moving northeast while those at the southern ends of the transects were moving southeast toward the coast.

An opportunistic transect was flown along the Baffin Island coast between the southern ends of the second and third transects to document the large numbers of whales we had observed there. Along this 5 km stretch of coast, a total of 1023 belugas and 129 narwhals were counted.

Table 1. Summary of sightings of narwhals and belugas recorded during 1984 aerial surveys of the Lancaster Sound ice edge and adjacent areas.

			Number of Narwhals							Number of Belugas						
			Transect[1]							Transect						
Survey	Date	Survey Period	1	2	3	4	5	6	1–6	1	2	3	4	5	6	1–6
1	27 June	Pre-disturbance	340	16	46	19	10	11	442	1734	158	39	65	52	21	2069
2	28 June	Primary disturbance	226	67	22	93	0	0	408	2874	82	0	131	36	0	3123
3	28 June	Primary disturbance	500	29	6	19	7	0	561	2332	235	2	45	0	6	2620
4	29 June	Primary disturbance	273	34	39	23	19	5	393	2329	200	55	26	22	17	2649
5	29 June	Primary disturbance	237	43	93	20	28	19	440	3122	226	23	42	33	147	3593
6	1 July	Secondary disturbance	73	35	20	16	38	12	194	2390	100	5	11	0	3	2509
7	2 July	Secondary disturbance	30	43	15	6	16	32	142	1030	78	28	34	37	23	1230

[1] Transects are numbered consecutively from the ice edge to the east.

Secondary Disturbance Period, 1-2 July 1984

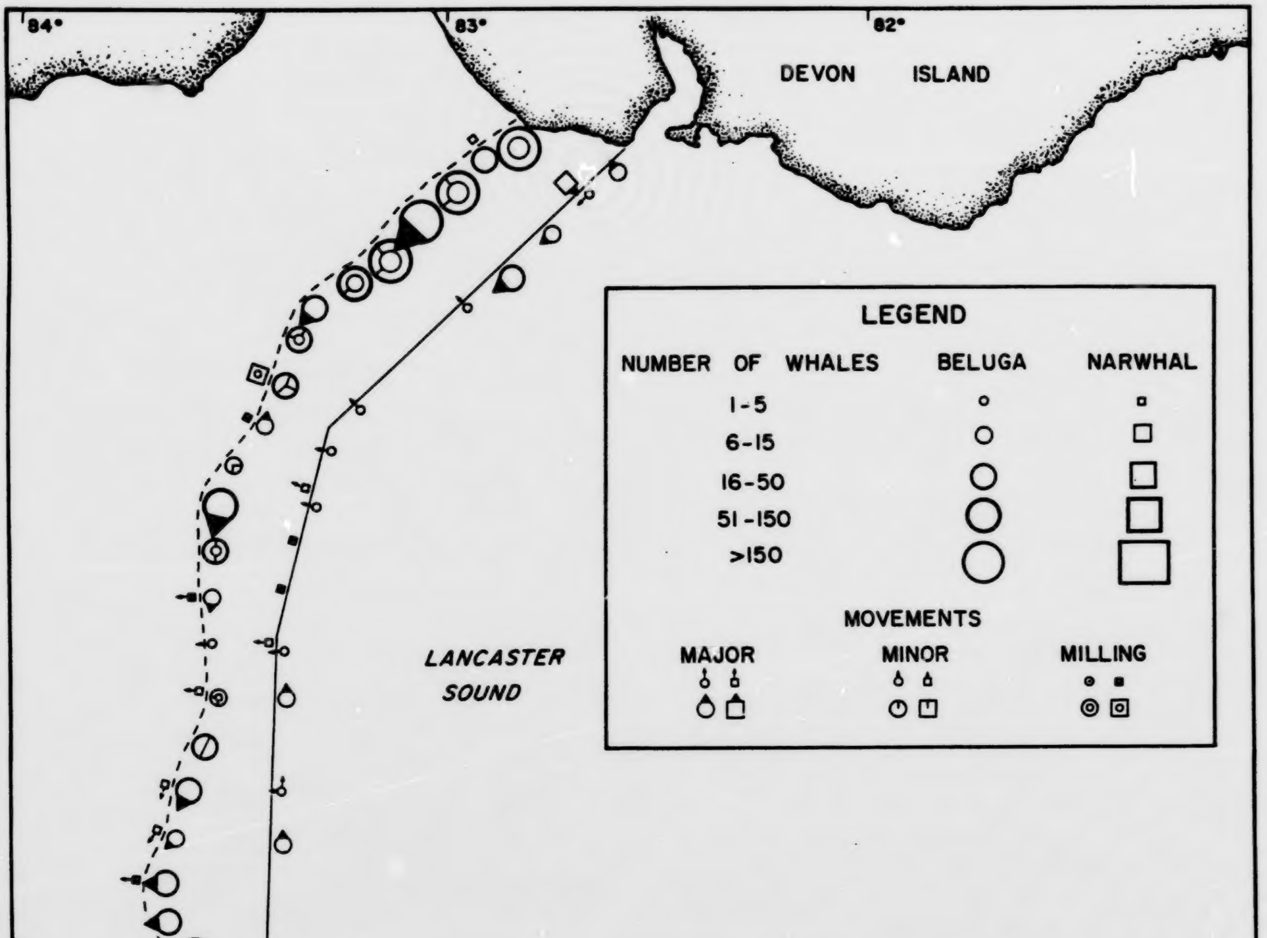
The ships began breaking ice during the survey in the early evening of 29 June. This process continued until the study was completed on 2 July, although the two ships were not moving continuously or at the same rate. Since the ships were moving southwest away from the ice edge, the level of potential disturbance to whales along the edge was decreasing. However, based on acoustic measurements made in 1982 and 1983 (Finley et al. 1983, 1984), it is apparent that ship noise would have been detectable at the ice edge throughout portions of this period when one or both ships were underway. However, noise levels would have been substantially lower than during the primary disturbance period, and progressively decreasing.

The ships operated during the night of 29-30 June. By 12:00 on 30 June, the Arctic was about 35 km west of the ice edge; she was due west of Cape Charles Yorke. The Louis St. Laurent was stopped during the afternoon of 30 June about 23 km due west of the ice edge at Cape Charles Yorke. The Arctic proceeded southwestward through the centre of Admiralty Inlet. At 12:00 on 1 July she was 50 km westsouthwest of the ice edge at Cape Charles Yorke. By 12:00 on 2 July, she was about 65 km distant. In the late evening of 30 June and early morning of 1 July, the Louis St. Laurent moved west across the entrance of Admiralty Inlet until 08:00 when she was 45 km due west of Cape Charles Yorke and 35-40 km from the ice edge. She remained in this vicinity until the surveys were completed on the morning of 2 July.

Survey 6, 1 July (p.m.)

No surveys were conducted on 30 June because the ships reported fog and poor visibility in the study area. When our 6th survey began (1 July, 15:20) the Arctic was about 50 km southwest of the ice edge and the Louis St. Laurent was about 45 km due west of Cape Charles Yorke and about 40 km westsouthwest of the ice edge.

Seventy-three narwhals were recorded along the ice edge (Fig. 7). This was fewer narwhals than had been recorded during any of the previous surveys. There was a large (31 km) gap in the distribution of narwhals along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>150
MOVEMENTS
MAJOR
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MILLING
Cape Charles Yorke
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BAFFIN ISLAND
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Figure 7. Distribution and directions of movement of narwhals and belugas recorded during survey 6, 1 July 1984 (15:20-17:20).

the edge that corresponded to the point where the ships entered the ice late on 29 June and the closest point to the present position of the Louis St. Laurent. The movements of the narwhals seen along the edge did not exhibit any particular pattern and appeared to be random, although many narwhals were diving under the edge, presumably feeding.

A total of 2390 belugas were seen along the ice edge. There was a gap in beluga distribution, identical in size to that observed for narwhals (31 km) but offset about 6 km to the south. Those belugas at the north and south ends of the ice edge were milling or resting near the edge, while those along the central portion of the edge were moving mostly south or west. Many of the belugas were diving or returning from dives under the ice edge, or resting near the edge; these behaviours were presumably related to feeding.

The 35 narwhals recorded on the transect 5 km east of the ice edge were scattered along the transect but 22 (63%) of these were concentrated near the Baffin coast. Movements of narwhals observed along this transect appeared to be random, although 24 whales (including the 22 seen near the Baffin coast) were moving west or southwest. The 100 belugas seen on this transect were well distributed along its length. Beluga movements seen on this transect were mostly south (51%) but substantial numbers were also moving north (22%) and west (24%).

Sightings of narwhals and belugas on the four eastern transects were concentrated toward the coastal segments of these transects. In this respect the distribution was similar to that observed along the comparable portions of the two transects located to the west of these. Thus, the zone that whales were absent from along the ice edge appeared to extend to the easternmost transects.

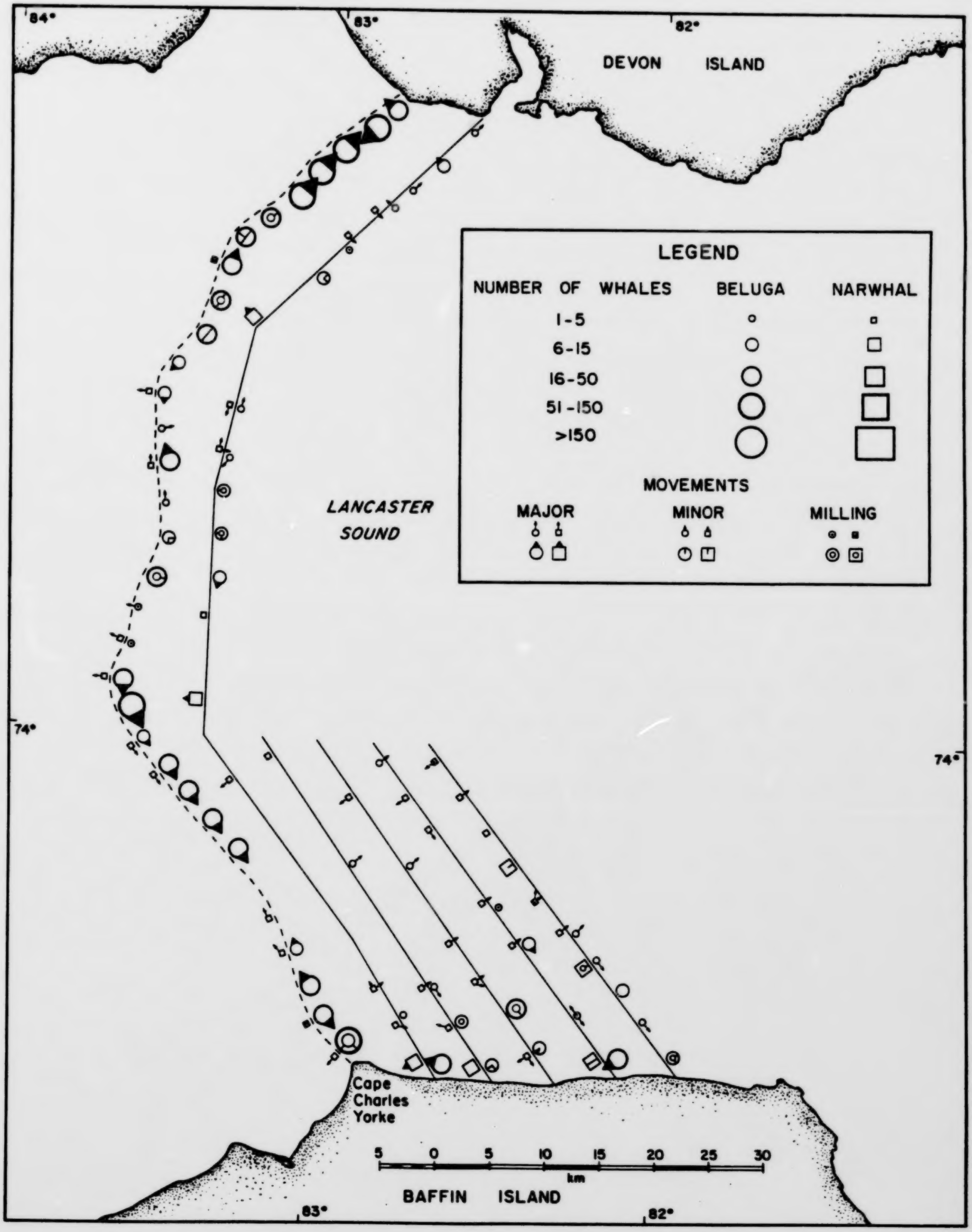
Survey 7, 2 July (a.m.)

As we approached Lancaster Sound on the morning of 2 July it was apparent that the ice in the sound had deteriorated considerably since we had last seen it, on 29 June. (There was no survey on 30 June, and low fog over Lancaster Sound on 1 July prevented us from determining whether cracking had occurred by that date.) By 2 July major cracks and leads hundred of metres wide had formed across the sound between the Brodeur Peninsula and Devon Island. At the time of the survey, the MV Arctic was about 60 km southwest of the ice edge. The Louis St. Laurent was about 35 km westsouthwest of the ice edge; it was not moving at the time of the survey (08:00) and had not travelled since the previous day.

The numbers of narwhals (142) and belugas (1230) seen during this survey were much lower than the numbers (194 and 2509, respectively) recorded the previous day (Table 1). Only 30 narwhals were seen along the ice edge and most of these were along the southern two-thirds of the ice edge (Fig. 8). There still appeared to be a small (14 km) gap in narwhal distribution along the section of the ice edge closest to the Louis St. Laurent. However, since so few narwhals were present along the entire edge, it is possible that this gap is merely a sampling artefact. Narwhals were moving in various directions but more were moving west (37%) than any other direction.

There was also a small (7 km) discontinuity in the distribution of the 1030 belugas observed along the ice edge. Otherwise belugas were well-distributed along the edge. Overall, there were approximately equal numbers of northbound (40%) and southbound (35%) belugas. Several large groups of whales along the northern portions of the ice edge were moving north while most of the southbound whales were located immediately north of the "gap" in beluga distribution. Belugas to the south of this gap were moving north so it is likely that the gap would have soon been closed.

The 43 narwhals recorded on the transect 5 km east of the ice edge were well distributed along the edge, except for a vacant section that corresponded to the gap in distribution observed along the ice edge. Narwhals along this transect were moving in all directions in a random pattern. The 78 belugas seen on this transect were found all along its length except for the same section in which narwhals were absent. Belugas were also moving in all directions.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MILLING
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Figure 8. Distribution and directions of movement of narwhals and belugas recorded during survey 7, 2 July 1984 (08:10-10:00).

Sixty-nine narwhals and 122 belugas were recorded on the four eastern transects. Numbers of both species were somewhat greater in the southern sections of the transects, but this tendency was less apparent on the easternmost lines. The overall distribution on these four lines indicates that whales were still less abundant in the area surrounding the potential disturbance area, but by the fourth short transect, 20 km east of the ice edge, this effect was almost negligible. Narwhals on these four transects were mostly moving northeast (58%), although a few whales were also observed moving toward most other directions. Belugas were also observed moving in various directions but were primarily heading southeast (33%) and southwest (26%). Substantial numbers were also either milling or motionless (25%).

The reduced numbers of whales recorded during this survey undoubtedly occurred because narwhals and belugas had entered the cracks and leads that had formed in the Lancaster Sound fast ice to the west. This behaviour was documented in the 1983 phase of this study (Finley et al. 1984) and has also been documented by Koski and Davis (1979) and Koski (1980). Regardless of this change in numbers of whales observed, it was apparent that even though the ice-breaker closest to the Lancaster Sound ice edge was 35 km from the ice edge, the distribution of narwhals and belugas along the ice edge and in adjacent areas remained affected by the present and/or prior activities of the ships. However, the effects on whale distribution were much less obvious during the 2 July survey than during 1 July.

DISCUSSION

Reactions to Ships

The results of the surveys in 1984 showed a very close correlation between the distribution and movements of whales and the activities of the ships.

The first survey (27 June) was clearly of animals that were unaffected by ship noise since the ships were about 300 km away and north of Devon Island. Belugas and narwhals were fairly evenly dispersed along the transects, with narwhals showing a preference for the south half of the ice edge (Fig. 2). The predominant direction of movement of both species was southward along the edge.

The first survey on 28 June began at the south end of the ice edge at 08:00--2 h after the MV *Arctic* arrived at the ice edge and 1 h before the CCGS *Louis St. Laurent* arrived. Major changes in the distribution of whales were apparent (Fig. 3). Virtually all of the narwhals and all of the belugas had vacated the ice edge and the offshore portions of the transects to the east, through which the ships had passed. Apart from four narwhals, no whales were seen along the southern 27 km of the ice edge. The closest belugas to the stopped *Arctic* were 20 km to the north. All whales (both species) seen along the ice edge 20 to 80 km north of the *Arctic* were swimming strongly to the north. Those along the northernmost 20-km segment of the ice edge, over 80 km from the *Arctic*, were mostly milling and circling near the edge.

The behaviour of the swimming belugas was somewhat similar to that seen in response to ships in the 1982 and 1983 phases of the study (Finley et al. 1983, 1984). The belugas were moving very rapidly, although the porpoising behaviour characteristic of immediate reaction was not particularly evident during this survey, which began two hours after the arrival of the *Arctic*.

We do not know how far from the ice edge the Arctic was when the whales first started to react. It is also not possible to say how far individual whales moved in response to the approaching ship. However, data from the next survey suggest that some whales moved at least 25 km. Most belugas moved considerably farther than 25 km given that belugas up to 80 km away were apparently still responding to the ship over two hours after the Arctic arrived.

The reactions of narwhals were less intense as evidenced by apparently slower swimming speeds than belugas. There was also evidence that some narwhals moved offshore from the ice edge in response to the ships.

The survey in the afternoon of 28 June indicated that whale behaviour was more normal and the animals were beginning to return to previously vacated sections of the ice edge (Fig. 4). The survey began 10 h after the Arctic, and 7 h after the Louis St. Laurent, reached the vicinity of the ice edge and shut down their main engines. In spite of the fact that onboard machinery was still generating some underwater noise, most narwhals and belugas were moving south along the ice edge toward the ships. The main movement of narwhals had reached a point about 10 km from the ships, whereas most of the belugas were still over 25 km from the ships.

The two ships started their engines and travelled about 15 km north along the ice edge before breaking into the ice and stopping at about 19:00 on 28 June. Our next survey began about 13 h later at 08:10 on 29 June. By this time narwhals were distributed all along the southern part of the ice edge (Fig. 5). There was no evidence of strongly directional movement or of reactions to the noise from machinery on the idle ships in the ice. Substantial numbers of narwhals had also re-occupied the offshore waters of the eastern transects.

The distribution of belugas during this survey (Fig. 5) indicated some avoidance of the ships even 13 h after the ships stopped their main engines. Belugas were present all along the ice edge north of the ships but none had moved past the ships to re-occupy that 20 km segment of the ice edge south of the ships. Belugas in the 25-30 km section of the ice edge north of the ships exhibited no net directional movement and were mostly milling or resting. Offshore, beluga distribution was apparently unaffected by the ships.

During the course of the second survey on 29 June, the ships started up, moved 7 km south along the ice edge, and began ice-breaking activities. Both narwhals and belugas reacted strongly during this activity. The easternmost transect was being surveyed as the ships began moving. On all four of the eastern transects both species of whales swam extremely rapidly. Belugas in pods were porpoising asynchronously in the surface waters. This type of "panic" response by belugas was also observed in response to approaching ships in both the 1982 and 1983 phases of the study (Finley et al. 1983, 1984).

Along the ice edge, narwhals and belugas were swimming rapidly away from the ships (Fig. 6). No narwhals were recorded in the 28 km north of the ship's start-up positions. (The narwhals immediately north of the ship positions indicated in Figure 6 were south of the advancing ships when they were observed.) Those to the south were swimming rapidly ahead of the southbound ships. During the previous survey in the morning, narwhals had been evenly distributed and stationary all along the southern third of the ice edge, including the area adjacent to the stationary ships. During the afternoon survey, the closest belugas to the ship's start point were about 13 km to the north. The majority (86%) of the 2649 belugas seen along the ice edge were swimming northward away from the ships. Even belugas as much as 80 km north of the ships' positions were swimming north 80 minutes after the ships first started moving. This major northward movement of belugas was in marked contrast to their behaviour during the previous survey 11 h earlier, when the ships were idle. During the earlier survey, 43% of the 2216 belugas north of the ships were milling and resting and 33% were moving south along the edge.

The final two surveys were conducted in the afternoon of 1 July and the morning of 2 July after the ships had penetrated southwest into the ice. The patterns of whale distribution during these two surveys are somewhat confounded by the fact that cracks and leads had formed in the ice to the west and some of the whales had undoubtedly moved into them. The survey on 1 July showed a gap in whale distribution along the southern third of the ice edge and on the eastern transects (Fig. 7). At the time of this survey, the Louis St. Laurent was about 40 km westsouthwest of the centre of this gap in whale distribution; she had shut down her engines about 7 h before our survey. The Arctic was about 50 km to the southwest. By the morning of 2 July, whale distribution was near normal with no significant gaps in distribution. At the time of the second survey (08:10-10:00), the Arctic was proceeding south through Admiralty Inlet about 60 km southwest of the ice edge. The Louis St. Laurent was stopped about 35 km westsouthwest of the ice edge. She had operated briefly late the previous evening. It is apparent from the 2 July data that the ships at these distances into the ice were having little, if any, effect on whale distribution.

Hunting

A potential complicating factor in the interpretation of the above aerial survey data is that some Inuit hunting of narwhals occurred along the ice edge during the survey period. The hunting took place northwest along the ice edge about 7 to 14 km from Cape Charles Yorke. Some of the observed changes in distribution might be accounted for as responses to the hunting rather than to the ships. However, the overall patterns of events, considered along with previous experience with narwhal hunts, suggest that hunting has only very localized effects on narwhal distribution.

Hunters were not present along the ice edge when we conducted our first survey (pre-disturbance) on 27 June. However, hunters arrived at the edge after our survey and killed and landed two narwhals before our second survey at 08:00 on 28 June. Survey 2 coincided with the arrival of the ships and major changes in whale distribution were occurring.

No narwhals were landed by the hunters between Survey 2 (08:00-10:00) and Survey 3 (16:00-18:00) on 28 June. This is not surprising since most of the whales had left the area during Survey 2. During Survey 3, whales were returning south along the ice edge and the main movement of narwhals was only a few km north of the hunters.

The hunters landed five narwhals after Survey 3 and before Survey 4 began at 08:10 on 29 June. It is apparent that this hunting had not affected narwhal distribution since narwhals were evenly distributed all along the southern third of the ice edge, including the area near the hunters' camps during Survey 4.

A single narwhal was landed between Surveys 4 and 5 (18:30 on 29 June). However, narwhal distribution during Survey 5 apparently was strongly affected by ship movements. In contrast, there was no evidence of a gap in the distribution of narwhals near the hunters. No further narwhals were taken during our study period.

The above analysis indicates that narwhal distribution was not affected on a large scale by Inuit hunting. This conclusion agrees with observations of narwhal hunts made by K.J. Finley (LGL Ltd., pers. comm.) who observed the Admiralty Inlet/Lancaster Sound hunt in 1982 and 1983 during the first two phases of this study. Additional observations from the ice edge hunt at Pond Inlet (three years) and open water hunts in several areas (Creswell Bay, Eclipse Sound/Pond Inlet, Clyde River) confirm the lack of anything but local movements (at most, a few km) by narwhals in response to hunting.

Other Factors

Other factors that could have influenced the observed behaviour and distribution of whales include ice conditions and food supply. The distributions of both narwhals and belugas can be directly influenced by ice conditions. Both species show strong preferences for areas of pan ice and pack ice at most times of the year (Davis and Finley 1979; Koski and Davis 1979, 1980; Koski 1980; McLaren and Davis 1981, 1982a,b). Throughout our study period, the ice edge remained free of pan ice accumulations. Small amounts of pan ice were present on the eastern five transects during some of the surveys. The amounts and distributions varied markedly among surveys and within transects during single surveys. There was no correlation between whale and ice distribution on these transects; whale distribution was obviously being governed by a factor completely independent of ice conditions.

If food supply was affecting day to day changes in whale distribution along the ice edge, then it would be necessary to assume that major changes in food availability along the edge occurred, which seems rather implausible. Studies of under-ice communities along ice edges in the Canadian arctic indicate that food organisms are relatively evenly distributed along ice edges at relatively stable levels in the time frame of our study (six days) (Bain et al. 1977; Bradstreet 1980, 1982a,b; Bradstreet and Cross 1982; Cross 1982). Similarly, the available evidence suggests that narwhals (and probably belugas) concentrate along ice edges in spring because the whales are waiting for cracks and leads to form so that they can proceed to their summering areas, rather than being attracted by food concentrations (Finley and Gibb 1982).

Finally, surveys of the Lancaster Sound ice edge in 1978 and 1979 demonstrated that belugas and narwhals were evenly distributed along the ice edge. Major discontinuities in distribution, such as occurred in 1984, did not occur in 1978 and 1979 when ship traffic was absent (Koski and Davis 1979; Koski 1980).

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